Published Monthly by
**American
Institute of
Electrical
Engineers**
(Founded May 13, 1884)

Electrical Engineering

Registered U. S. Patent Office

September 1936
Volume 55
No. 9

The Official Monthly Journal and Transactions of the AIEE

A. M. MacCutcheon, President
H. H. Henline, National Secretary

Publication Committee

I. Melville Stein, Chairman
C. O. Bickelhaupt
J. W. Barker
O. W. Eshbach
H. H. Henline
L. W. W. Morrow
D. M. Simmons
W. R. Smith
W. H. Timbie

Publication Staff

G. Ross Henninger, Editor
Floyd A. Lewis, Associate Editor
C. A. Graef, Advertising Manager

PUBLICATION OFFICE, 20th and Northampton Streets, Easton, Pa.

EDITORIAL AND ADVERTISING OFFICES, 33 West 39th Street, New York, N. Y.

MAIL should be sent to New York address

ENTERED as second class matter at the Post Office, Easton, Pa., April 20, 1932, under the Act of Congress March 3, 1879. Accepted for mailing at special postage rates provided for in Section 1103, Act of October 3, 1917, authorized on August 3, 1918.

SUBSCRIPTION RATES—$12 per year to United States, Mexico, Cuba, Porto Rico, Hawaii, and the Philippine Islands, Central America, South America, Haiti, Spain, and Spanish Colonies, $13 to Canada, $14 to all other countries. Single copy $1.50.

CHANGE OF ADDRESS—requests must be received by the fifteenth of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge. Both old and new addresses should be given, as well as any change in business affiliation.

ADVERTISING COPY—changes must be received by the fifteenth of the month to be effective for the issue of the month succeeding.

STATEMENTS and opinions given in articles and papers appearing in "Electrical Engineering" are the expressions of contributors, for which the Institute assumes no responsibility. Correspondence is invited on all controversial matters.

REPUBLICATION from "Electrical Engineering" of any Institute article or paper (unless otherwise specifically stated) is hereby authorized provided full credit be given to the author or authors and to the Institute.

COPYRIGHT 1936 by the American Institute of Electrical Engineers.

ELECTRICAL ENGINEERING is indexed annually by the Institute, weekly and monthly by *Engineering Index,* and monthly by *Industrial Arts Index,* abstracted monthly by *Science Abstracts* (London).

Printed in the United States of America. Number of copies this issue—18,300

This Month—

Front Cover

Two 500-kva 750-kv 60-cycle transformers for making high voltage tests at normal frequency at the laboratory of the Ohio Brass Company, Mansfield. A similar transformer is housed in an adjacent building, and the 3 units may be connected in cascade to provide 60-cycle testing voltages of 2,250 kv, outdoors. Each transformer is mounted on a porcelain tile base.

Special Articles

A Message From the President 951
By A. M. MacCutcheon
An Analysis of Electrical Engineering Graduates 952
Membership Activities 954
By Everett S. Lee

AIEE Papers

A D-C Controlled Voltage Regulator 956
By Paul H. Odessey
A Transmission System for Teletypewriter Exchange Service . . 961
By R. E. Pierce and E. W. Bemis
Parallel Inverter With Inductive Load 970
By C. F. Wagner
Heater-Cathode Insulation Performance 981
By Hans Klemperer
Impulse Voltages Chopped on Front 985
By P. L. Bellaschi
Electrical Measurement of Silk Thread Diameter 991
By O. Hugo Schuck
A New Telephotograph System 996
By F. W. Reynolds
An Analysis of the Shaded Pole Motor 1007
By P. H. Trickey
Switchboards and Signaling Facilities of the Teletypewriter Exchange System 1015
By A. D. Knowlton, G. A. Locke, and F. J. Singer
A Disturbance Duration Recorder 1025
By C. H. Frier
The Control Gap for Lightning Protection 1029
By Ralph Higgins and H. L. Rorden

—Turn to next page

Discussions

Tests on Lightning Protection for A-C Rotating Machines—Hunter 1035

Equivalent Circuits—2 Coupled Circuits—Balsbaugh, Douglass, Gow, Leal 1037

Frequency Tripling Transformers—Cantwell . . 1039

Electrical Equipment for Waterworks Systems—Canariis 1039

News 1040

South West District Meeting Offers Attractive Program 1040
AIEE Directors Meet at Institute Headquarters . . 1042
Technical Conferences Held During Summer Convention 1043

Future AIEE Meetings 1042

Letters to the Editor 1045
Professional Aspects of Engineering Education
Voltage Regulation of Alternators
Revised Sphere-Gap Spark-Over Voltages

Membership 1050

Engineering Literature 1055

Industrial Notes 1056

Officers and Committees 1051

Employments Notes (See Advertising Section)

In This Issue—

TELETYPEWRITER service in which the time required for connecting subscribers is comparable with that required in making long distance telephone connections has been established in the United States on a nationwide basis. This system consists of teletypewriters for sending and receiving with connections to a nearby switching center, transmission channels interconnecting all switching centers, and switchboards for connecting subscriber stations and transmission channels. The transmission system designed for this teletypewriter exchange service is described in this issue (*pages 961–70*). Specially designed switchboards and signaling facilities adapted to this service also are required (*pages 1015–25*).

INSULATION between heater and cathode of modern electronic tubes usually consists of a coating about 0.5 millimeter thick on the surface of the heater wire. This insulating coating must conduct heat from heater to cathode while maintaining high electrical resistance at operating temperatures. Laboratory investigations show that impurities and heat treatment of this insulation during manufacture materially affect the performance of the tubes (*pages 981–5*).

TELEPHOTOGRAPHY has been improved greatly since its introduction several years ago so that now pictures as large as 11 by 17 inches can be transmitted directly from the original photographs. Equipment newly designed for this improved service, described in this issue, includes arrangements for daylight operation, a new type of driving motor, and scanning with a pulsating beam of light whereby the photoelectric current can be amplified by a-c methods (*pages 996–1006*).

QUALITY of service rendered by a power system as well as the ability of generating plants to continue in synchronous operation depends largely upon the length of time a fault is allowed to remain on the system. A simple disturbance duration recorder recently developed has been in successful use on a western power system and has proved effective not only in locating faulty relays and breakers, but also in indicating where improvements in relaying might be made (*pages 1025–8*).

CONTROL GAPS for protecting power system equipment unfortunately do not have flashover characteristics similar to those of the insulation to be protected. However, by controlling the dielectric field about such a gap the so-called time-lag characteristics can be varied at will and made to conform to almost any desired curve (*pages 1029–34*).

MEASUREMENT of the thread diameter is of primary importance in determining the quality rating of raw silk thread. An electrical method of measuring and recording this nonelectrical quantity has been developed, which depends for its operation on changes of capacitance as variations in thread diameter move the jaws of a caliper (*pages 991–6*).

IMPULSE VOLTAGES chopped on the rising fronts of the waves can occur on electric power transmission lines, and for that reason laboratory studies of such waves have been undertaken. Results so far indicate that waves of this character are much more difficult to produce, control, and apply than are fully developed waves (*pages 985–90*).

A VOLTAGE regulating transformer has been developed in which the application of direct current to an additional winding varies the core saturation and hence the output voltage. Tests on a model show that a wide range of regulation may be obtained and that the output wave form is not distorted (*pages 956–60*).

DALLAS, Texas, will be the scene of a 3-day meeting of the Institute's South West District on October 26–28. The complete program is announced in this issue (*pages 1040–2*). One of the principal attractions will be the Texas Centennial Exposition now being staged in that city (*page 960*).

SHADED-POLE motors are said to be the most popular of the various types of small single-phase motors now being built, especially for ratings less than $^{1}/_{30}$ horsepower. A mathematical analysis of this type of motor is presented in this issue, and its performance characteristics are discussed (*pages 1007–14*).

OFFICERS AND COMMITTEES elected and appointed to serve the Institute during the coming year are listed in this issue; also the Institute's 62 Sections and 117 Branches (*pages 1051–5*).

CHARACTERISTICS of a parallel static inverter utilizing electronic tubes of the grid-controlled mercury-vapor type have been calculated for inductive loads (*pages 970–80*).

STATISTICS show an average of 2,809 electrical graduates annually during the 8-year period ending 1935, from 135 colleges in the United States (*pages 952–3*).

REPORTS of 2 additional technical conferences held during the AIEE 1936 summer convention have become available (*page 1043*).

SECTIONS of the Institute are urged to survey their membership abilities and to put those abilities to work (*pages 954–5*).

READERS of ELECTRICAL ENGINEERING continue to express their views on a variety of subjects in the "Letters to the Editor" columns (*pages 1045–6*).

Revised Sphere-Gap Spark-Over Voltages

Supplementing the partial report published on page 783 of the July 1936 issue of ELECTRICAL ENGINEERING, the subcommittee in charge advises that the tabulated values given are crest values and should be so designated and used. Standards for impulse voltages are expected to be ready for publication within the next few months. AIEE Standard No. 4 is in the process of revision by the Institute's committee on instruments and measurements.

A Message From the President

Text of an address delivered June 22, 1936, in Pasadena, Calif., at the annual business meeting held in connection with the summer convention, in response to the notification of election

FIFTY-TWO years ago the pioneers in the field of electricity laid the foundation of a society to be known as the American Institute of Electrical Engineers; dedicated to the principles of advancing the theory and practice of electrical engineering and of the allied arts and sciences, and the maintaining of a high professional standing among its members. Since that time (and prior to today), 48 engineers have been notified of their election to the presidency of that society. I wish that I might know the feeling and emotion of each one of these engineers on the day that he was advised of his election, and whether there was a single one that was able to find adequate words in which to express his appreciation of the great honor that had been conferred upon him.

History should be our greatest teacher, and it is my intention to become familiar not only with the technical achievements of these men, but to know of their personal and professional characteristics, aims, and ambitions. For from the lives and achievements of such men as Norvin Green, Edward Weston, Elihu Thompson, Alexander Graham Bell, Frank Sprague, A. E. Kennelly and the 41 others whom time does not permit me to enumerate, should come the greatest inspiration, stimulus and guidance to an incoming president of the Institute.

Alexander Morton MacCutcheon
AIEE President 1936–37

Even these intellectual giants of the electrical profession must have been overwhelmed by the honor done them and the responsibilities placed upon them through their election to the highest office that can be conferred upon a member of the Institute. How much more overwhelming these honors and responsibilities appear to me. I can but place my trust in the axiom, "What man has done, man can do," and President Meyer's statement, "There is no failure except in no longer trying."

Inspired by the example of those who have preceded me, and if supported by every individual, District, Section, Branch, and member of the Institute, I feel that it is not impossible for us, all working together, to carry this organization to still greater heights of achievement. "Co-operation is vital if our aims, our purposes, our ideals are to be realized."

It is indeed most fortunate that the constitution of the Institute provides for the senior and junior past-presidents to continue their services on the board of directors. For, if this year we have a fair measure of success, the guidance and counsel of President Meyer and Past-President Whitehead will very largely be responsible.

Searching for some basis of individual distinction, I am much gratified to find that I am the first to receive this announcement at a convention actually held on the Pacific Coast, and the second who has had the honor of being notified of his election at a combined summer and Pacific Coast convention.

The eighth and ninth geographical Districts are among the most active and successful in our organization, contributing much to technical information through the papers presented at the winter, summer, and Pacific Coast conventions and challenging their eastern brethren by their enthusiasm and devotion to the work of the Institute. The welcome which Los Angeles extends to us today, and the completeness with which the activities of this convention have been planned causes regret that distance has prevented the attendance of many devoted AIEE members from the East who seldom miss a convention. For the first time in the history of the Institute, the reception committee traveled 650 miles to extend their greeting.

You have conferred upon the Cleveland Section the highest honor that can be conferred upon any Section, in electing one of its members to the presidency of the Institute. No words are adequate to express their appreciation of this honor.

The Middle Eastern District (No. 2) which includes Cleveland, shares in the honor that you have bestowed. With the co-operation and support of the Cleveland Section, District 2, all the Districts and Sections from Canada to Mexico, and every individual member throughout the world, I feel that we can look forward with confidence to success in carrying on the traditions and activities of this great engineering organization.

A M MacCutcheon

An Analysis of Electrical

A survey of electrical engineering graduates for the 8 year period ending 1935, conducted by the Eta Kappa Nu Association, honorary electrical engineering society, shows that 2,809 (average) have graduated annually from 135 American colleges during that period. The year 1934–35 appears to be the "low point" of both the 8 year period and the succeeding 4 years.

TO determine the effect of changing economic conditions during recent years on the supply of electrical engineers, the Eta Kappa Nu Association conducted a comprehensive survey in which the numbers of graduates from all recognized American colleges for the 8 year period, 1927–28 to 1934–35, were secured.

Information on courses, degrees, hours of work required for various subjects, qualifications of the faculty and facilities available was obtained from every college in the country that teaches electrical engineering. A careful appraisal of all of these factors was made to determine which colleges should be included in the survey, the principal requirements for inclusion being that the college offered a 4 year course or its equivalent, leading to the degree of BS in EE or its equivalent. All institutions offering only 3 year courses or less were omitted, even though some of them grant a BS degree. It was necessary also to omit certain colleges that offer a general engineering course, including some electrical engineering subjects. A certain number of the graduates of these colleges do enter electrical work but in general their electrical training is considerably less than that offered in straight electrical engineering courses. Where colleges offer both a 3 year and a 4 year course the figures were obtained only for the longer.

The period of 8 years was selected so that an accurate picture could be obtained of what happened when the

Number of Electrical Graduates From

College and Location	Course, Years	Degree	Number of EE Graduates by Years 1927–28	1928–29	1929–30	1930–31	1931–32	1932–33	1933–34	1934–35
Akron, University of, Ohio[1]	5	B of EE	4	6	7	12	5	6	4	4
Alabama Polytechnic Institute, Auburn	4	BS in EE	55	59	39	38	43	28	35	37
Alabama, University of, University	4	BS in EE	8	13	13	13	11	20	13	22
Antioch Col., Yellow Springs, Ohio[2]	5	BS			6	3	3	3	0	1
Arizona, University of, Tucson	4	BS in EE	8	6	7	13	5	4	7	4
Arkansas, University of, Fayetteville	4	BS in EE	6	9	9	7	12	5	13	11
Armour Inst. of Technology, Chicago	4	BS in EE	28	47	32	36	30	36	32	28
Brooklyn, Poly. Inst. of, N. Y	4	BS in EE	20	32	32	30	38	40	32	45
Bucknell University, Lewisburg, Pa	4	BS in EE	10	15	4	8	9	6	6	9
California Inst. of Tech., Pasadena	4	BS in EE	15	16	27	15	28	16	26	24
California, University of, Berkeley	4	BS in EE	55	51	53	46	49	55	55	72
Carnegie Inst. of Tech., Pittsburgh	4	BS	20	20	32	36	33	40	41	34
Case School of Applied Sc., Cleveland	4	BS in EE	27	17	21	26	34	26	30	18
Catholic University, Washington	4	B of EE	9	7	8	4	9	8	13	9
Cincinnati, Univ. of, Ohio[1]	5	EE	20	31	22	21	26	17	24	16
Clarkson Col. of Tech., Potsdam, N. Y	4	BS in EE	24	26	20	13	18	18	25	16
Clemson Agr. Col., Clemson Col., S. C	4	BS	40	23	27	18	30	26	38	25
Colorado State College, Fort Collins	4	BS	12	14	14	13	12	10	10	8
Colorado, University of, Boulder	4	BS in EE	43	31	33	31	51	42	31	43
Columbia University, New York[3]	5	EE	6	9	8	15	12	14	14	13
Connecticut State College, Storrs[4]	4	BS in Eng								
Cooper Union, New York	4	BS in EE	13	13	15	15	19	12	23	10
Cornell University, Ithaca, N. Y.[5]	4	EE	42	62	49	37	38	40	26	47
Dayton, University of, Ohio	4	BS in EE	9	16	10	7	9	7	12	13
Delaware, University of, Newark	4	B in Eng	9	17	11	9	14	12	7	13
Denver, University of, Denver	4	BS in EE	6	8	12	7	7	6	10	7
Detroit Inst. of Tech., Mich.[1]	5	BS	4	3	5	5	5	9	4	2
Detroit, University of, Mich.[1-3]	5	BS in EE	17	7	26	16	29	17	16	11
Drexel Institute, Philadelphia[1-7]	5	BS in EE	29	2	21	31	41	38	33	30
Duke University, Durham, N. C.[8]	4	BS in EE								
Emory University, Atlanta	4	BS in Eng	1	4	0	3	0	1	6	3
Fenn College, Cleveland[2]	4	BS in EE			6	6	9	8	15	19
Florida, University of, Gainesville	4	BS in EE	12	7	13	17	19	16	16	16
George Washington Univ., Washington	4	BS in EE	6	10	8	6	15	7	3	7
Georgia School of Technology, Atlanta	4	BS in EE	53	46	41	71	74	79	88	57
Gettysburg College, Gettysburg, Pa	4	BS in Eng	5	3	4	3	4	1	1	4
Harvard University, Cambridge, Mass	4	BS in EE	11	13	14	8	5	7	8	6
Howard University, Washington[9]	4	BS in EE	2	2	0	1	2	2	3	0
Idaho, University of, Moscow	4	BS in EE	10	18	11	20	13	11	13	21
Illinois, University of, Urbana	4	BS	67	68	67	68	55	69	71	55
Iowa State College, Ames	4	BS in EE	50	54	53	47	46	40	42	38
Iowa, University of, Iowa City	4	BS	10	15	17	26	23	21	18	23
John B. Stetson Univ., DeLand, Fla.[10]	4	BS in Eng					2	3	5	3
Johns Hopkins University, Baltimore	4	BS in Eng	19	16	11	12	21	12	17	19
Kansas State College, Manhattan	4	BS in EE	42	51	55	50	46	45	44	46
Kansas, University of, Lawrence	4	BS in EE	27	29	27	24	24	22	37	6
Kentucky, Univ. of, Lexington[11]	4	BS in ME	32	38	42	38	34	44	36	25
Lafayette College, Easton, Pa	4	BS in EE	12	8	7	10	12	8	11	6
Lawrence Institute of Technology, Highland Park, Mich.[1-12]	5	BS in EE						2	4	8
Lehigh University, Bethlehem, Pa	4	BS in EE	30	36	40	29	13	17	20	18
Lewis Institute, Chicago	4	BS in EE	16	22	9	13	11	21	23	16
Louisiana Poly. Institute, Ruston[13]	4	BS in M-EE	8	7	8	14	13	13	21	23
Louisiana State Univ., Baton Rouge	4	BS in EE	18	14	21	19	25	23	25	20
Louisville, University of, Ky	4	BS in EE	6	7	3	15	7	4	7	3
Maine, University of, Orono	4	BS in EE	21	32	26	24	24	20	21	22
Manhattan College, New York[14]	4	B of EE								
Marquette University, Milwaukee[1]	5	B of EE	19	29	30	20	13	23	14	22
Maryland, University of, College Park	4	BS	13	10	11	12	16	15	18	21
Mass. Inst. of Tech., Cambridge[15]	4	BS in EE	179	163	133	142	132	132	109	87
Mich. Col. of Mining & Tech., Houghton[16]	4	BS in EE				12	16	21	27	21
Michigan State College, East Lansing	4	BS	26	17	22	30	14	18	15	16
Michigan, Univ. of, Ann Arbor[17]	4	BS in Eng	62	44	46	55	61	36	51	47
Milwaukee Sch. of Engg., Milwaukee[18]	4	BS in EE	15	15	20	36	28	57	47	25
Minnesota, University of, Minneapolis	4	B of EE	65	66	90	70	52	53	59	59
Mississippi State Col., State College	4	BS	49	25	24	39	39	39	29	22
Missouri Sch. of Mines & Met., Rolla	4	BS in EE	10	11	10	9	12	7	8	16
Missouri, University of, Columbia	4	BS in EE	19	25	30	21	8	15	17	8
Montana State College, Bozeman	4	BS	30	32	22	22	27	11	14	14
Nebraska, University of, Lincoln	4	BS in EE	30	23	30	30	24	18	22	16
Nevada, University of, Reno	4	BS in EE	19	7	9	9	11	6	15	12

Notes 1 to 16: (1) Co-operative course. (2) First EE graduates in 1929–30. (3) Figures are for the 5 year course, leading to a BS or EE degree. (4) No EE graduates until 1937–38. (5) Figure for 1934–35 includes 14 who received a BS in Administrative Engineering, with specific reference to EE. (6) All graduates to 1932–33, 14 in 1933–34 and 6 in 1934–35 received a BEE degree. Two in 1933–34 and 5 in 1934–35 received a BS in EE degree. (7) Changed from a 4 year to a 5 year course in 1928–29. (8) Figures not furnished. (9) For colored students. (10) First EE graduates in 1931–32. (11) Figures are for a combined electrical and mechanical engineering course. An electrical engineering course, leading to a BS in EE degree, was started in 1935–36. (12) First EE graduates in 1932–33. (13) Combined electrical and mechanical engineering course. (14) Course recently established. No EE graduates yet. (15) A 5 year co-operative course leads to an MS in EE degree. (16) First EE graduates in 1930–31.

Engineering Graduates

Essential substance of a report by Clifford A. Faust (A'35) president, national executive council of Eta Kappa Nu, published in the June-July 1936 issue of "The Bridge of Eta Kappa Nu", presented here at the request of the AIEE committee on education and with the consent and co-operation of the Eta Kappa Nu Association.

American Colleges—1927–28 to 1934–35

College and Location	Course, Years	Degree	Number of EE Graduates by Years							
			1927 –28	1928 –29	1929 –30	1930 –31	1931 –32	1932 –33	1933 –34	1934 –35
New Hampshire, Univ. of, Durham	4	BS	21	11	20	21	13	14	17	22
New Mexico State Col., State College	4	BS in EE	5	2	3	7	6	8	7	9
New Mexico, Univ. of, Albuquerque	4	BS in EE	2	3	10	5	3	5	2	5
New York, College of the City of,[19]	4	BS in Eng	6	7	17	10	3	11	14	13
New York University, New York	4	BS in EE	10	19	16	17	12	20	28	13
Newark College of Engg., N. J.[20]	4	BS in EE	16	17	18	20	25	20	23	25
North Carolina State College, Raleigh	4	SB in EE	27	18	23	28	19	29	20	19
North Carolina, Univ. of, Chapel Hill	4	BS in EE	12	7	15	14	14	11	7	8
North Dakota Agricultural Col., Fargo	4	BS in EE	3	5	7	4	10	16	18	14
North Dakota, Univ. of, Grand Forks	4	BS in EE	10	9	8	6	10	5	10	6
Northeastern University, Boston[17–21]	5	BS in EE	63	86	94	70	103	13	56	60
Northwestern Univ., Evanston, Ill	4	BS in Eng	13	12	11	10	8	16	7	9
Norwich University, Northfield, Vt	4	BS in EE	17	6	11	11	15	6	11	8
Notre Dame, U. of, South Bend, Ind	4	BS in EE	20	26	17	20	25	24	24	12
Ohio Northern University, Ada	4	BS in EE	8	14	15	11	14	12	8	7
Ohio State University, Columbus	4	B of EE	60	38	44	40	37	36	23	15
Ohio University, Athens[22]	4	BS in EE		7	6	5	7	6	8	9
Oklahoma A. & M. College, Stillwater	4	BS in EE	13	22	27	17	16	22	20	11
Oklahoma, University of, Norman	4	BS in EE	19	12	25	19	21	22	18	31
Oregon Inst. of Technology, Portland	4	BS in EE	2	5	8	10	9	9	13	4
Oregon State College, Corvallis	4	BS	51	42	27	41	30	21	24	30
Pacific Col. of the, Stockton, Calif	4	BA	0	1	1	4	1	0	0	0
Pennsylvania State Col., State College	4	BS in EE	71	69	68	65	62	63	65	61
Pennsylvania, Univ. of, Philadelphia	4	BS in EE	19	24	12	15	13	9	14	14
Pittsburgh, University of, Pa	4	BS in EE	18	10	18	26	29	31	21	20
Princeton University, Princeton, N. J	4	BS in Eng	4	9	2	6	10	6	8	3
Purdue University, Lafayette, Ind	4	BS in EE	94	135	122	123	128	120	120	121
Rensselaer Poly. Inst., Troy, N. Y	4	BS in EE	83	57	78	84	69	86	98	72
Rhode Island State College, Kingston	4	BS in EE	14	14	15	6	8	6	7	19
Rice Institute, Houston	4	BS in EE	10	7	9	11	12	9	10	10
Rose Poly. Inst., Terre Haute, Ind	4	BS in EE	22	15	14	16	18	13	16	10
Rutgers Univ., New Brunswick, N. J	4	BS in EE	7	9	4	6	11	14	15	15
Santa Clara, Univ. of, Calif.[23]	4	B of EE	8	3	7	12	12	11	8	6
South Carolina, Univ. of, Columbia	4	BS in EE	2	6	9	4	4	8	10	4
South Dakota State College, Brookings	4	BS in EE	16	15	18	11	19	12	9	9
S. Dak. St. Sch. of Mines, Rapid City	4	BS in EE	14	14	20	16	17	16	13	12
South Dakota, Univ. of, Vermillion[24]	4	BS in Eng	7	10	4	1	6	6		
Southern Calif., Univ. of, Los Angeles	4	BS in EE	13	12	15	18	14	9	14	12
Southern Methodist Univ., Dallas[17–25]	4	BS in EE			3	9	7	7	7	8
Stanford University, Palo Alto, Calif	4	AB in Eng	24	25	19	23	22	17	18	9
Swarthmore College, Swarthmore, Pa	4	BS in Eng	2	4	3	5	4	2	4	1
Syracuse University, N. Y	4	BS in EE	10	18	12	24	20	22	14	16
Tennessee, University of, Knoxville	4	BS in EE	13	9	13	20	19	22	17	14
Texas, A. & M. Col. of, Col. Station	4	BS in EE	47	44	54	55	41	46	37	32
Texas Technological College, Lubbock	4	BS in EE	1	4	5	8	13	11	10	8
Texas, University of, Austin	4	BS in EE	22	22	9	33	30	28	28	25
Toledo, Univ. of, Ohio[17–18]	5	B of Eng								
Tufts College, Medford, Mass	4	BS in EE	7	12	9	9	8	20	12	13
Tulane University, New Orleans[26]	4	B of Eng	10	8	12	8	10	11	15	16
Union College, Schenectady, N. Y	4	BS in EE	25	9	15	23	22	21	18	14
Utah, University of, Salt Lake City	4	BS in EE	17	12	16	14	15	10	11	14
Valparaiso Univ., Valparaiso, Ind	4	BS in EE	1	0	1	5	0	6	4	5
Vanderbilt Univ., Nashville, Tenn.[27]	4	B of Eng	4	4	8	5	9	6	5	4
Vermont, University of, Burlington	4	BS in EE	16	14	5	6	8	10	9	7
Villanova College, Villanova, Pa	4	BS in EE	4	7	12	11	6	12	16	14
Virginia Military Inst., Lexington	4	BS in EE	22	18	20	23	23	30	36	18
Virginia Poly. Institute, Blacksburg	4	BS in EE	52	40	37	34	40	42	43	29
Virginia, Univ. of, Charlottesville	4	BS in Eng	4	6	13	7	4	6	7	8
Washington, State College of, Pullman	4	BS in EE	37	27	31	23	28	22	22	30
Washington University, St. Louis	4	BS	22	21	21	16	17	13	14	18
Washington, University of, Seattle	4	BS in EE	38	38	34	32	31	37	34	36
Wayne University, Detroit[28]	4	BS in EE							5	5
West Virginia University, Morgantown	4	BS in EE	17	15	24	21	17	13	16	20
Wisconsin, University of, Madison	4	BS in EE	66	51	40	52	43	60	54	50
Worcester Poly. Inst., Worcester, Mass	4	BS in EE	38	43	30	29	31	36	34	37
Wyoming, University of, Laramie[28]	4	BS in EE	0	5	7	7	10	6	6	6
Yale University, New Haven, Conn	4	BS in EE	14	18	17	12	11	13	6	8
Total of all EE graduates			2826	2779	2831	2881	2891	2782	2868	2614
EE's from colleges not having graduates over entire 8 yr period			7	23	33	47	61	62	77	80
Total of EE's from colleges having graduates over the entire 8 yr period			2796	2756	2798	2834	2830	2720	2791	2534

effect of the depression on enrollment became felt. As may be seen in the totals in the accompanying table, the maximum number of EE graduates was 2,891 in 1931–32. For the first 7 years of the period the total number of graduates varied from 2,779 to 2,891, a difference of only 112. In 1934–35, the total dropped to 2,614, an indication that the first freshman class to be affected seriously was the one that entered in the fall of 1931.

Early reports from a few colleges on the number of graduates for 1935–36 indicate that the total will show a small increase over last year, and reports on the number of students in the under classes show that the number of graduates will continue to increase for the next 3 years. Apparently, the 1934–35 class will prove to be the smallest in the period of the 8 year study and the 4 succeeding years.

During the 8 year period a total of 22,472 electrical engineers were graduated, or an average of 2,809 per year. While the demand for electrical engineering graduates has increased considerably in the past 2 years, it would be optimistic indeed to expect that every one of the 2,800 graduates will find perfectly satisfactory employment without special effort. Every senior should consider himself in competition with approximately 2,800 other men who have satisfactorily completed a regular 4 year course or its equivalent in a recognized American college. Even though employment opportunities continue to increase there will always be keen competition for the better positions.

Notes 17 to 28: (17) The regular 4 year course and the 4 year plus 16 months co-operative course lead to a BS in Eng. (EE) degree. A 5 year course leads to an MS in Ind. EE degree. (18) Figures are for the calendar years 1928 to 1935, inclusive. (19) The full course is 5 years, leading to an EE degree. (20) Same course may be distributed over 5 years. (21) All EE graduates from 1927–28 and 1931–32 and 7 in 1932–33 took a 4 year co-operative course, leading to a B of EE degree. (22) First EE graduates in 1928–29. (23) 1927–28 graduates received a BS in EE degree, those in 1928–29 a B in EE degree, and all from 1929–30 to 1934–35 a B of EE degree (24) College of engineering discontinued at close of 1932–33. (25) A 5 year co-operative course also leads to a BS in EE degree. (26) Combined electrical and mechanical engineering course, leading to a B of Eng. in M-EE degree. (27) Combined electrical and mechanical engineering course. Figures are an approximation of those specializing in EE. (28) First EE graduates in 1933–34.

Membership Activities

By Everett S. Lee, Director AIEE

Chairman, National Membership Committee 1933–36

IT HAS been my happy privilege to serve for 3 years as chairman of our national membership committee. This year I come before you with convictions that have grown more firm as I have seen the results of the membership activities during this time.

I entered the work of the national membership committee 3 years ago, secure in the feeling that our Institute was fundamentally sound; that it represented the best; that it had *made* the profession. I saw the Sections of the Institute, 60 of them, reaching from where I was in Schenectady to Pittsfield, Springfield, Worcester, Lynn, and Boston in Massachusetts; Providence, R. I.; and the Connecticut State Section to the New York metropolitan Section; to the Lehigh Valley and Philadelphia Sections in eastern Pennsylvania; Baltimore, Md.; Washington, D. C.; and then ranging through the southern states to Virginia, North Carolina, Florida, Atlanta, Ga., Alabama, Louisville, Ky., St. Louis, Mo., Memphis, Tenn., and Mexico City; Houston, San Antonio, and Dallas, Texas; Oklahoma City, Okla.; Kansas City, Mo.; Nebraska; thence west to Denver, Colo., the Utah State Section, and up the Pacific Coast from Los Angeles through San Francisco, Portland, Ore., Seattle, Wash., Vancouver, B. C., and back through Spokane, Wash., to the Montana State Section; up into Canada to the Saskatchewan Section, thence to the Minnesota and Iowa State Sections; Madison and Milwaukee, Wis.; Chicago and Urbana in Illinois; Fort Wayne and Central Indiana Sections; Cincinnati, Columbus, Akron, Cleveland, and Toledo in Ohio; Detroit-Ann Arbor in Michigan; Pittsburgh, Sharon, and Erie in western Pennsylvania; up to Toronto, Ontario; thence to the Niagara Frontier Section at Buffalo, and Rochester, Ithaca, Syracuse, and back to Schenectady.

I saw meetings in each of these Sections on an average of more than 8 evenings yearly with a total attendance of 73,806 engineers, or an average of 148 in each meeting.

I saw 111 Student Branches similarly covering the United States and portions of Canada, and in the schools where they were located I saw meetings of bright eager students, to the total number of 59,439 or an average of 58 meeting on an average afternoon in 1,026 meetings; and later I saw half of these students come into Associate membership in the Institute, as they became workers in the field of their profession.

I saw a headquarters in New York in an Engineering Societies Building. I saw a monthly periodical with the latest and newest contributions of the members of the profession. I saw participation in an American Engineering Council, in United Engineering Trustees. I saw standards written by the members of the profession. I saw technical and general committees. I saw conventions for the presentation of papers and the meeting of minds.

I saw a live, virile organization. I saw the life-giving organization of the electrical engineering profession. Not only I, but many others saw these, our heritage from those who had gone before. And today I see the same picture, augmented by the results of all of us who have contributed as we have been able. Today: 61 Sections functioning (New Orleans Section organized December 8, 1933), another authorized, and 3 under consideration; 118 Student Branches in operation.

To me, the Sections are the Institute, and you, the Section chairmen, together with your associated officers hold the key to the success of our venture. The members of the Institute will largely feel its active pulse as your Section covers the range of abilities of your Section membership. To the extent that the total activities of your Section draw upon and enlarge the total abilities of your Section membership, the program which you and your officers are directing may be considered adequate. Survey your Section membership abilities, put these abilities to work; your office will be a pleasure because of the fruits.

HOW SOME SECTIONS ARE DOING IT

Now, I am going to bring to your attention some specific examples of where Sections have done this:

New York Section. Four technical groups were established in 1929: communication, illumination, power, and transportation. Meeting from 2 to 7 times yearly, in addition to general Section meetings, these groups have averaged 3 meetings annually over a period of 7 years, except the power group, which has averaged 5 meetings annually. Participation in activities of each group is open to the entire Section membership, and notices of all meetings are sent to all members. Attendance and interest have exceeded expectations. The power group has been conducting courses in structures (for license examinations), effective speaking, and review of electrical engineering principles. A course in electronics was started recently. Proposed courses in economics and business law are under consideration. A report covering the development of New York Section group activities and describing various present activities of the power group was published in ELECTRICAL ENGINEERING for April 1936, pages 421–2.

Chicago Section. A power group was established in 1929, and has held from 2 to 6 (average 4) meetings each year since. Attendance and enthusiasm

---

Text of address delivered by Everett S. Lee (A'20, F'30) as the retiring chairman of the Institute's national membership committee, before the annual conference of officers, delegates, and members, held June 22, 1936, in connection with the summer convention at Pasadena, Calif.

have remained high, and this group activity is recognized by the Chicago Section as a very important part of its work.

Pittsfield and Schenectady Sections. Since 1930, 2 annual joint meetings have been held, one in each city, for competition among members of not more than 30 years of age in presenting their initial papers. Two prizes, $15 and $10, are awarded at each meeting.

San Francisco Section. For 2 years special technical meetings have been held between regular Section meetings. Six such meetings have been held each year, and have given members more opportunity to participate and to receive information of special interest. Further, the Section has received benefits through larger attendance and greater interest in the Institute. A Section *Bulletin* containing notices of future meetings, reports of past meetings, personal items, reports of local committees, references to national activities, etc., is sent to members each month. A comprehensive report on these and other activities of this Section was published in ELECTRICAL ENGINEERING for April 1935, page 454.

Portland Section. In the fall of 1934, 3 technical committees were organized: communication, industrial power applications, and transmission and distribution. During the year 1934–35, these groups held respectively 6, 9, and 7 meetings. Two additional committees were formed in the fall of 1935. Meetings of these groups as reported for 1935–36 were: communication 5, electrochemistry and electrometallurgy 4, illumination 6, transmission and distribution 15. Committee meetings have enabled a much larger number, especially of younger members, to participate in Section activities. Activities of these technical committees were reported in ELECTRICAL ENGINEERING for September 1935, page 1010.

Boston and Lynn Sections. Annually a joint meeting is held for competition among members for prizes. Papers are judged on the basis of oral presentation. The first such meeting was held in the spring of 1935, with 6 papers, 3 from each Section, presented and 3 prizes awarded. The 1936 meeting was held April 21, with 4 papers from each Section and prizes of $25, $20, $15, and $10 offered.

Niagara Frontier Section. The executive committee decided on November 25, 1935, that the Section should organize 2 technical discussion groups: one concerned with the generation, transmission, and distribution of electricity, and the other concerned with electrical communication. No later information has been received.

Philadelphia Section. During a period of 18 weeks in 1935–36 a course in electronics was conducted, limited to members of the Institute, with fee of $12 paid in advance. Instead of the expected enrollment of from 20 to 25, an actual enrollment of 53 necessitated the formation of 2 classes, with a net profit to the Section of $118.50 instead of an expected small deficit. The enthusiasm was such that that Section has been requested to repeat the course next year and to provide a continuation course. Also there is a demand for courses covering mathematics review, electrical theory review, and so forth. A report covering the interesting details of this work was published in ELECTRICAL ENGINEERING for August 1935, p. 933–34.

Cleveland Section. A technical division in the field of motors and control was established in the fall of 1935. The 2 meetings held proved the experiment to be even more successful than was expected. The Section officers expect to organize other technical divisions later.

Sharon Section. During 1935–36, 2 technical discussion meetings were held.

Seattle Section. The February meeting each year is devoted to a competition among members of the Section for a $25 prize offered for the best paper.

Toledo Section. A news bulletin is sent to members monthly.

Undoubtedly there are many others, but these suffice to give a picture of what is being done. You Section officers are the ones to continue it and to enlarge it and augment it.

SOMETHING FOR NOTHING—?

I have had many letters come to me during the last few years asking "Why not do this," and "Why not do that." I want to give just one typical instance. One of my friends wrote to me suggesting a reduction of the entrance fee, "to make it easier for new members to enter." In my reply I tried to get across the important thought that the new member enters a group already enriched by every member that has preceded him, a factor which, although of small proportions in the beginning, had grown because of the liberal expenditure of time and money through a period of a half-century. The entrance fee is but his capitalization of this heritage, and what a low figure for such rich a heritage! Some months later my friend wrote to tell me that 10 of the members of his staff had joined the Institute, unbeknown to him, and had paid the initiation fee. Why? Because they found their abilities were being drawn upon by the Section in a recognition of their worth and their needs. I could repeat such instances, but time does not permit.

The report of the membership committee for the past year to the board of directors is in your hands. (ELECTRICAL ENGINEERING, July 1935, p. 798–9.) It shows the result of the constant labors of your Section membership committees so effectively rendered, a net increase in members, the first yearly increase since 1931. I commend the report to your study. But, beyond this, I commend the thought that your Section program include every member in those purposes for which the Institute was founded and has lived. As you do this, the membership of our Institute will maintain the profession in the high place in which it stands today, and membership activities will be fruitful.

A D-C Controlled Voltage Regulator

A voltage regulating transformer, having a core so designed that the application of direct current to an additional winding will vary the core saturation and hence the output voltage, is described in this paper. Tests on a model constructed on this principle have shown that a wide range of regulation may be obtained, and that the wave form is not distorted.

By
PAUL H. ODESSEY
ENROLLED STUDENT AIEE
Brooklyn, N. Y.

A SIMPLE METHOD of voltage regulation in distribution systems has become an increasingly important need. In the past, development tended largely toward the improvement of the older types of voltage regulators with the result that the transformer regulators now widely used differ only slightly in design. These transformers are usually designed with taps and require somewhat intricate mechanisms to change taps under load. Another type of voltage regulator in common use is the induction regulator, which is a transformer having fixed and rotatable windings. To regulate voltage, the rotor is turned by a mechanical device consisting of a motor and a system of gears. This type of regulator gives a smooth variation in voltage, whereas the tap-changing transformer gives a variation in steps. In both, however, the method of voltage regulation is burdened with mechanical difficulties.

The investigation of a simpler method of voltage regulation has led to the development of a new transformer voltage regulator controlled by direct current. This type of regulator affords a simple and direct method of voltage regulation and has several advantages over the older types. The regulator, consisting of a transformer provided with a d-c winding, is designed as a single unit, and depends upon partial saturation as a means of voltage control.

Recent regulator systems employing this principle consist essentially of 2 units, a transformer and a saturated reactor connected in series. By means of saturation the voltage across the reactor is varied, thereby controlling the transformer voltage. The transformer voltage regulator as described in this paper operates in a similar manner, but the properties of the saturated reactor are incorporated in the transformer.

The advantages of the d-c controlled transformer regulator may be briefly summarized as follows:

1. The method of voltage regulation is simple and direct.
2. There are no moving parts or contacts.
3. The variation in voltage is smooth and the control instantaneous.
4. The amount of power required to control the voltage over a wide range is relatively small.
5. The operation of the regulator is independent of line fluctuations and is capable of maintaining constant voltage.
6. Service need not be interrupted in case of failure in the control circuit since the transformer and regulating d-c winding are not interconnected.
7. No adjustments or replacements are required in the operation of the regulator.
8. The transformer is a flexible source of variable voltage and may be operated by remote control.

The problem of voltage regulation resolves itself fundamentally into the control of the induced voltages. In presenting this subject some elementary principles of the transformer might be considered. The induced voltages in the primary and secondary windings of a transformer may be expressed as

$$E_1 = kN_1\Phi \quad (1)$$

$$E_2 = kN_2\Phi \quad (2)$$

where k is a constant, N the number of turns, and Φ the maximum value of the flux. The subscripts 1 and 2 refer to primary and secondary respectively.

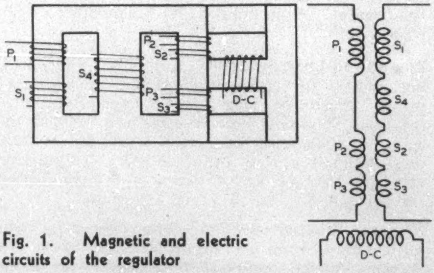


Fig. 1. Magnetic and electric circuits of the regulator

From equation 2 it may be seen that in order to increase the secondary induced voltage, either the number of turns or the flux must be increased. In most static transformers, the secondary has a fixed number of turns, thereby making the flux the only variable quantity. The magnitude of flux, however, is dependent upon the number of turns and the induced voltage of the primary as given by equation 1. Since the primary induced voltage is approximately constant for a given impressed voltage, it is evident

---

A paper presented at the annual student Branch convention of the New York City District (No. 3) April 26, 1935, and subsequently awarded the Institute's 1935 Branch paper prize; recommended for publication by the AIEE committee on award of Institute prizes and by the electrical machinery committee. Manuscript submitted February 13, 1936; released for publication May 28, 1936.

that if the number of turns on the primary is reduced, the flux must increase in order to maintain the primary induced voltage. Accordingly, the secondary induced voltage increases in proportion.

This method of voltage control is used in tap changing transformers in which a special contact arrangement is employed to change the number of turns on the primary. The problem in designing a new transformer voltage regulator, based on the same principle, was to find some means of reducing the effective number of turns on the primary without actually removing the turns from the circuit. A study of the saturated reactor showed the possibility of accomplishing this effect.

THE SATURATED REACTOR

The saturated reactor is a variable impedance device consisting essentially of 2 coils wound on an iron core, one for alternating current and the other for direct current. The d-c winding is used to produce a flux which is variable, depending upon the magnitude of the current and permeability of the iron core. The a-c winding is used for insertion in a circuit to control the current by its variable impedance. Inductance is the determining factor in the impedance of this winding, and it is proportional to the permeability of the iron core.

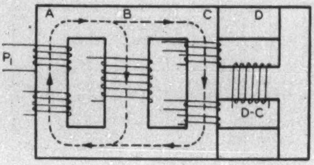


Fig. 2. Flux distribution produced by the primary coil P_1

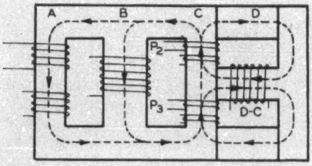


Fig. 3. Flux distribution produced by the primary coils P_2 and P_3

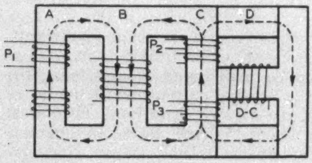


Fig. 4. The normal flux distribution produced by the entire primary

If the d-c winding is not excited and the a-c winding is inserted in a circuit containing impedance, the current in the coil will produce an alternating flux which is dependent upon the permeability of the iron core. If, now, the d-c winding is excited so that the core becomes saturated with continuous flux, the inductance and alternating flux will be greatly reduced by the decrease in permeability, thereby, changing the impedance of the reactor from a relatively high value to a low value. The voltage drop across the reactor decreases in the same manner, thereby increasing the current in the circuit. Thus by saturation the inductance or the effect of a given number of turns may be reduced by changing the permeability of the iron core.

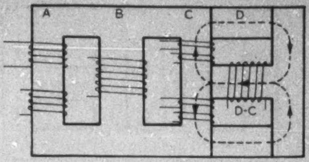


Fig. 5. Flux distribution produced by the d-c winding

In a closed magnetic circuit of this kind, however, wave shape distortion in both current and reactor voltage results when a continuous flux is superimposed upon an alternating flux because of the nonlinearity of the saturation curve. Clearly, the direct application of this principle as a means of voltage control in transformers is not feasible, since constancy in wave shape is of paramount importance.

In order to incorporate the principle of d-c saturation in the practical design of a transformer, the following conditions are imposed:

1. That saturation should be restricted to only one portion of the iron core.
2. That the wave shape of the induced voltage and exciting current should not be affected by saturation.
3. That no alternating voltage should be induced in the d-c winding.

To satisfy these conditions a transformer regulator having a magnetic circuit of the type shown in figure 1 was designed. The core requires standard laminations and is built with minimum reluctance.

Referring to figure 1, coils labeled P and S are respectively primary and secondary and are arranged as shown. Coils P_2 and P_3, together with S_2 and S_3, are identical windings. The d-c winding is located on the middle leg of the outer portion.

Electrically, all coils, both in the primary and secondary, are connected additively in series. The magnetic relations are not quite evident, and in order to obtain a clear understanding of the flux relationships, the flux distribution produced by each coil acting alone may be considered.

In figure 2 is shown the flux distribution produced by P_1. Field lines indicate the direction of flux in the legs A, B, and C. Because the outer section D has relatively high reluctance due to the length of path and joints, the amount of flux in this path is negligible and may be omitted without causing error.

Considering P_2 and P_3 as a group, the flux distribution is given by figure 3. Since these coils are in series, the field lines will be in the same direction within A, B, and C. In the middle leg of section D, however, the magnetomotive forces produced by

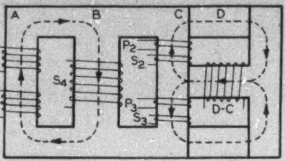


Fig. 6. Effective flux produced by excitation of both primary and d-c windings

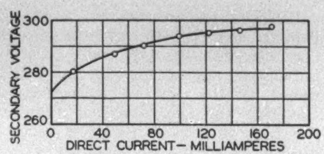


Fig. 7. No-load characteristic obtained with model transformer

P_2 and P_3 are equal and opposite, resulting therefore in a neutralization of a-c flux. Under these conditions no alternating voltage will be induced in the d-c winding. This is an important factor as it eliminates the possibility of alternating voltage drops occurring in the d-c winding and reflecting their effect back into the transformer.

By combining figures 2 and 3 the normal a-c flux distribution is obtained as shown in figure 4. In leg *A* the flux is in the direction indicated because the magnetomotive force of P_1 across *A* is greater than that of P_2 and P_3. A similar condition exists in leg *C* where the magnetomotive force of P_2 and P_3 is greater than that of P_1. In leg *B* the field lines are in the same direction as is evident.

In figure 5 is shown the flux distribution produced by the d-c winding. Inasmuch as the distribution is symmetrical with respect to the transformer core no d-c flux exists in either leg *A* or leg *B*. Therefore, with the d-c winding in the position shown, it is possible to saturate only leg *C*. Another point to be noted is that the d-c flux in the upper portion of *C* is opposite to that in the lower portion. Thus it is evident that distortion produced by saturation in one direction is neutralized exactly by the same effect in the opposite direction. Under these circumstances the wave shape of the induced voltage and the exciting current will not be affected by saturation.

In consideration of the secondary it will be sufficient to say that its magnetic reaction upon the transformer core is similar to that of the primary. This relation is true under all conditions of operation.

THEORY OF OPERATION OF THE REGULATOR

The operation of the transformer regulator may be best understood by considering the specific case when continuous voltage is applied to the regulating winding, and the transformer is supplying load. Because of saturation the a-c flux in *C* will be greatly reduced thereby causing, in effect, a shift in applied voltage from primary coils P_2 and P_3 to P_1. Since this is equivalent to a reduction in the number of primary turns, the flux must increase and will be distributed as shown in figure 6. For simplicity, the small amount of flux in leg *C* under saturated conditions has been omitted in this figure and only the effective flux distribution is considered.

It is evident that by saturating leg *C* the voltage in the coils S_2 and S_3 decreases. However, the increase in flux through coils S_1 and S_4 is sufficient to produce a substantial increase in total secondary voltage. This follows from the fact that saturation affects a greater percentage of the primary turns than of the secondary turns.

EXPERIMENTS WITH MODEL TRANSFORMER

Using a small model transformer of this design tests were conducted to determine the operating characteristics. In figure 7 is shown the no load characteristic which was obtained by varying the direct current and measuring the corresponding secondary voltage. The normal load characteristic for a resistance load is given in figure 8. The drop in voltage from no load to maximum load is 36 volts, indicating a voltage regulation of 13.2 per cent. In a test conducted using direct current as a means of voltage regulation, the secondary terminal voltage was maintained constant throughout the range of load, as indicated by the upper curve in figure 8.

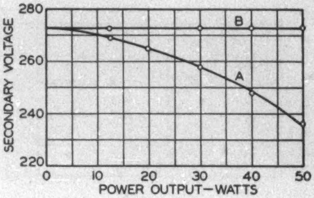


Fig. 8. Load characteristics of model transformer

A—Normal
B—With d-c control

An oscillograph record showing the effect of partial saturation upon the wave shape of secondary voltage and exciting current is given in figure 9. The voltage waves, while not quite sinusoidal, show clearly that the method of saturation does not affect the wave shape. Indirectly, however, the relatively high leakage reactance of the model transformer was modified through a redistribution of the a-c flux, thus improving slightly the wave shape of the voltage. That the principle of saturation is fundamentally correct may be further seen by considering the wave shape of the exciting current, which would be considerably altered if any distortion effect were produced. This is not the case, as the oscillograms clearly indicate no change in wave shape whatever.

THE REGULATOR AS A SOURCE OF VARIABLE VOLTAGE

In laboratories and in certain fields of electrical engineering manually operated voltage regulators are used frequently as sources of variable voltage. For this purpose the d-c controlled transformer, because of its smooth voltage characteristic and wide range of voltage, may be used to advantage.

In investigating its possibilities as a source of variable voltage, the same arrangement as just described was used. By reversing coil connections, either in the primary or secondary, various voltages were obtained. The effect of d-c saturation produced either an increase or decrease in secondary voltage, depending upon whether the coils connected in series were aiding or opposing. In any case, a smooth variation in voltage over a wide range was obtained. The results of a few tests are plotted in figure 10, and show clearly the flexibility of the d-c controlled transformer voltage regulator as a source of variable voltage. Oscillograph tests made in connection with these tests indicated a variation in voltage wave shape over the range of saturation. This may be attributed to the unbalanced magnetic conditions between primary and secondary caused by arbitrary coil connections. In addition, it must not be overlooked that the model transformer, characterized by relatively high resistance and leakage reactance, affected results to a considerable extent. The last mentioned is a matter of design and may be remedied without great difficulty.

APPLICATIONS OF THE REGULATOR

It may be readily seen that the d-c controlled transformer voltage regulator is well adapted for automatic control. By using a voltage sensitive element consisting of either a nonlinear bridge or a contact-making voltmeter operating in conjunction with a grid-controlled mercury-vapor tube automatic voltage regulation may be obtained. It should be pointed out, however, that although the d-c output of the tube is pulsating, the possibility of wave shape distortion is eliminated because of the unique arrangement of the d-c winding. The d-c controlled transformer voltage regulator in this form has for one of its most outstanding features simplicity and a pure electrical control.

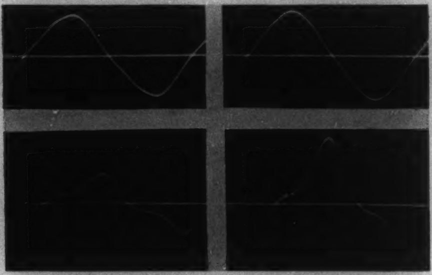


Fig. 9. Oscillograms of secondary voltage (top) and exciting current (bottom) obtained with model transformer

Left hand oscillograms for normal transformer; right hand oscillograms with d-c control

As a source of variable voltage, the transformer voltage regulator has a wide field of application both in the laboratory and in industry. Lighting control, such as required in the theater, the starting of certain types of a-c machinery, and other controlling may be simplified by the use of the regulator.

At present, experiments with the model transformer indicate that a few refinements in design must be made in order to meet the requirements of power service. Toward this end, further study has been made and experiments are now in progress at the Polytechnic Institute of Brooklyn. For the purposes of investigation, however, it has been shown that in many ways the development of the d-c controlled transformer voltage regulator points to a simplified method of voltage regulation.

ADDENDA

In the design of a d-c controlled transformer regulator, the geometric disposition of both primary and secondary windings plays an important part. Inasmuch as the magnetic circuit must provide a path for the main alternating flux when a continuous flux is superimposed on a restricted portion of the iron core, a 3 legged section (excluding that for direct current) is the simplest type that can be used. The leakage reactance of such an arrangement is relatively high as compared to ordinary transformers because the windings are symmetrically located about the center leg. While this may not be objectionable in view of short circuit conditions, it is undesirable for normal operation. However, due to the ability of the transformer regulator to maintain its terminal voltage, this characteristic is not a serious drawback. The effect of primary leakage reactance upon the

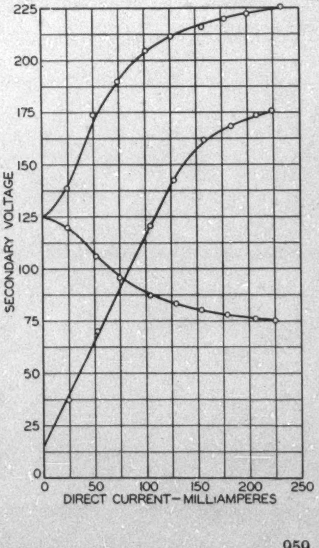


Fig. 10. No-load voltage characteristics of model transformer obtained by 3 different connections of the coils

wave shape of secondary voltage must be given careful consideration. A transformer with high leakage reactance introduces considerable harmonics into the induced voltage. Windings with the proper number of turns are arranged with magnetic symmetry to balance out harmonics.

Leakage reactance is also influenced by the type of flux distribution used. For the type of magnetic circuit under consideration, 2 kinds are obtainable:

1. That type of distribution in which the fluxes produced by P_1, P_2, and P_3 are in the same direction in the center leg, as described hereinbefore.
2. That type of distribution in which the flux produced by P_1 is opposed to the fluxes of P_2 and P_3 in the center leg.

A study of these considerations, also taking into account the optimum arrangement of windings, will determine the minimum leakage reactance of the magnetic system.

The range of operation of the transformer regulator for a given cross section and arrangement of windings is limited to the maximum change in flux density. For this reason the transformer is normally operated at low flux density in order to meet the requirements of regulation. Accordingly, the increase in exciting current is kept within a reasonable limit, although the change may be as much as 150 per cent. As a result of the geometric disposition of windings, the maximum change in coupling will be an additional factor contributing to regulation.

For automatic control, the use of a nonlinear bridge[1,2] as a voltage sensitive element operating in conjunction with a grid-controlled mercury-vapor tube for d-c excitation might be suggested. As these elements have been already developed and employed in practice,[3,4] a discussion concerning their operation would seem to be out of place in an original investigation.

REFERENCES

1. A VOLTAGE SELECTIVE NONLINEAR BRIDGE, C. G. Suits. *Physics*, v. 1, Sept. 1931, p. 171–81.
2. NEW APPLICATIONS OF NONLINEAR CIRCUITS TO RELAY AND CONTROL PROBLEMS, C. G. Suits. A.I.E.E. TRANSACTIONS, v. 51, 1932, p. 914–21.
3. AN ELECTRONIC VOLTAGE REGULATOR, P. H. Craig and E. F. Sanford. ELECTRICAL ENGINEERING (A.I.E.E. TRANSACTIONS) v. 54. Feb. 1935, p. 166–70.
4. AN ELECTRONIC REGULATOR FOR AN ALTERNATOR, C. C. Whipple and W. E. Jacobsen. ELECTRICAL ENGINEERING (A.I.E.E. TRANSACTIONS) v. 54, June 1935, p. 663–7.

Airplane view of the Texas Centennial Central Exposition, which will be one of the principal attractions for those attending the Institute's South West District meeting to be held at Dallas, October 26–28, 1936

A Transmission System for Teletypewriter Exchange Service

A nationwide transmission system has been established in the United States for teletypewriter exchange service by means of which 2-way communication between teletypewriter subscribers can be established in a time comparable with that required for long distance telephone service. A brief description of the principle of operation of teletypewriters is included in this paper as an introduction to the discussion of the transmission requirements and the plan of the present system.

By
R. E. PIERCE
MEMBER A.I.E.E.
E. W. BEMIS
MEMBER A.I.E.E.

Both of the American Telephone & Telegraph Co., New York, N. Y.

TO MEET the growing needs of business organizations, particularly those operating on a nationwide basis with branches at widely separated locations, there has developed in the United States an extensive use of private line telegraph service. This trend has been accelerated by the perfection of the teletypewriter, which makes it possible for regular office employees to transmit and receive communications without a large amount of special training. Some of these private line teletypewriter networks have been provided with switching facilities to permit the customer to set up connections between his various offices or groups of offices as desired. As these arrangements were perfected and as the public gained experience with the teletypewriter method of communication, a demand developed for a teletypewriter service in which all connections would be set up on a switched basis similar to that provided for spoken conversation by the telephone system. To meet this demand teletypewriter exchange service or as it is usually called, *TWX* service, was inaugurated by the Bell System in November 1931.

Briefly described, teletypewriter exchange service makes available to subscribers a complete communication system for the written word, consisting of:

a. Teletypewriters for sending and receiving, installed on the customers' premises with a connection to a nearby switching center.

b. Transmission channels interconnecting all of the switching centers.

c. Teletypewriter switchboards for connecting the subscribers' stations and loops to each other or to the intercity transmission channels and for making through connections between intercity circuits.

This system provides for direct teletypewriter connections between the customers or their employees at the sending point and at the receiving points. The connection is 2 ways so that questions can be asked and answers given. The speed with which the connection is established is comparable with that experienced in long distance telephone service, the average being about 1.3 minutes from the time a subscriber calls the operator until the conversation between subscribers begins. The service has grown until at the present time there are over 8,500 subscriber stations which may be connected together in pairs or in groups for teletypewriter communication. The switching is done at about 150 switching centers scattered throughout the United States as shown in figure 1 and connected by over 500,000 miles of telegraph circuit.

This paper deals primarily with the transmission system used for passing the teletypewriter code signals between the customers. The details of the switchboards and signaling facilities, and the methods of handling customers' connections are described in another paper.[1] With the exception of the switchboards, the equipment used in *TWX* service is similar to that used in other telegraph services.

The teletypewriters are provided with a keyboard similar to that of a typewriter for sending, and the typing is done in capital letters either on a narrow tape or on a page, the page being used in the large majority of the stations. Printed forms may be used on the page machines if desired. The speed of operation is set for a maximum of 60 words per minute. The teletypewriters are of the start-stop type, using a 5 unit selecting code, each group of selecting impulses being preceded by a start impulse and followed by a stop impulse. The teletypewriter mechanism is operated from a local source of power, and in general all signaling current is furnished from central office power plants.

The line circuits may be any of the well known types utilizing 2 current values or line conditions of variable duration for the transmission of signals. Actually about 90 per cent of the circuit mileage used in the *TWX* service is of the carrier type, since this is the most economical type of facility for large groups over the longer distances. The line circuits will be discussed in more detail in another section of the paper.

A paper recommended for publication by the A.I.E.E. committee on communication and scheduled for discussion at the A.I.E.E. South West District meeting, Dallas, Texas, October 26–28, 1936. Manuscript submitted March 28, 1936; released for publication June 1, 1936.

[1] For all numbered references see list at end of paper.

ELEMENTS OF TELETYPEWRITER SIGNAL TRANSMITTING AND RECEIVING MECHANISM

To translate intelligence which is received in the form of a code the receiving mechanism must be capable of doing 2 things. First, it must identify the unit time intervals, and second, it must determine which of the 2 line conditions should be recorded for each time interval. The first requisite is accomplished by maintaining a high degree of synchronism between the sending and receiving devices during the transmission of each character. The second is accomplished by providing satisfactory transmission facilities so that the midportion of each received signal element is the same as the corresponding signal element at the sending end.

TIMING ARRANGEMENTS

The sending and receiving devices are driven by motors which run at approximately the same speed. The receiving device is driven through a friction clutch so that it normally may be idle even though its motor is running. When a signal is received the receiving selector is released, makes one complete revolution, and again comes to rest. With this arrangement it is necessary to maintain synchronism only while one character is being transmitted, because a fresh start is made for each character, and the time intervals for the selecting impulses are measured from this starting point. Cumulative lack of synchronism, therefore, over long periods of time does not affect the accuracy of transmission. This is called the start-stop system.

The advantages of this arrangement are as follows:

a. No elaborate means of synchronizing are required.

b. The lag in the line is automatically taken care of because the receiving machine does not start until the first signal of a code combination is received.

c. Multisection circuits and conference connections can be set up without any special line-up.

d. Machines can be started and shut down without any special adjustment.

e. Local power sources can be used for driving the subscriber's machine.

In actual practice speed is maintained within ± 0.75 per cent in either of 2 ways:

1. Where regulated frequency a-c power is available, synchronous motors ordinarily will maintain the speed within ±0.17 per cent, which is well within the limit necessary for satisfactory transmission.
2. Where regulated frequency a-c power is not available, governed motors are used for either alternating or direct current. These governors are designed so as to maintain the speed within ±0.75 per cent without attention over long periods of time. If the speed of the sending machine is out in one direction and that of the receiving machine in the opposite, the maximum difference may be 1.5 per cent.

Assuming no deformation of the wave shape between the sender and the receiver, the start-stop teletypewriter operating at 60 words per minute will stand about 7 per cent speed discrepancy before errors occur. In practice, however, there is deformation and therefore the speed discrepancy must be kept as low as practicable.

SENDING AND RECEIVING ARRANGEMENTS

The sending arrangement in a teletypewriter is required to do 3 things:

1. It must transmit a signal which will start the selecting cycle of the distant machine.
2. It must apply the proper current condition to the line for each of the 5 accurately spaced selecting time intervals.
3. It must send a signal which will return the line to the normal idle condition.

The teletypewriter operates in a local circuit in which current is flowing during the normal idle condition. The transmitting is done by opening and closing this circuit, causing zero current or normal current in it, the 2 conditions being referred to as "open" and "closed." The selecting cycle of the distant machine is initiated by opening the circuit at the sending teletypewriter. This is called the "start" signal. The 5 selecting signals follow and the line current during each of these time intervals depends upon the character which is being transmitted. Since the normal idle condition of the line is closed, the "stop" signal which is sent last in the train of signals is a "closed" signal.

The selecting arrangement in a receiving teletypewriter is also required to do 3 things:

1. It must start timing the signals when the start signal is received.
2. It must determine the line condition at the midpoint of each selecting interval.
3. It must come to rest during the stop interval following the 5 selecting signals.

A single electromagnet in the receiving machine converts the electrical pulses into mechanical operations of the selecting mechanism. This magnet controls an armature which is energized for the closed line condition and de-energized during the open line condition. By this means the 2 line conditions are converted into 2 positions of the magnet armature.

THEORY OF TELETYPEWRITER SIGNAL TRANSMISSION

In teletypewriter signal transmission at 60 words per minute (hereafter called 60-speed) the start pulse and each of the 5 selecting signal elements are normally of 0.022 second duration. The minimum length of the stop pulse is 0.031 second. In keyboard sending the maximum length of stop pulse depends upon the time the operator hesitates between the striking of the individual keys of the teletypewriter. Any lengthening or shortening of the signal elements in transmission is referred to as distortion and is expressed as a percentage of the normal length of a signal element. The fundamentals of signal transmission have been discussed thoroughly by various writers.[2,3,4] A few of these principles are enumerated here without any attempt to discuss them thoroughly.

1. With the transmitting arrangements usually employed the complete change in line condition at the sender is practically instantaneous.
2. To transmit accurately these sudden changes in the line condition would require a transmission channel capable of passing an infinitely wide frequency band.
3. With a transmission channel which will pass only a limited band of frequencies there will be alteration of the wave shape during

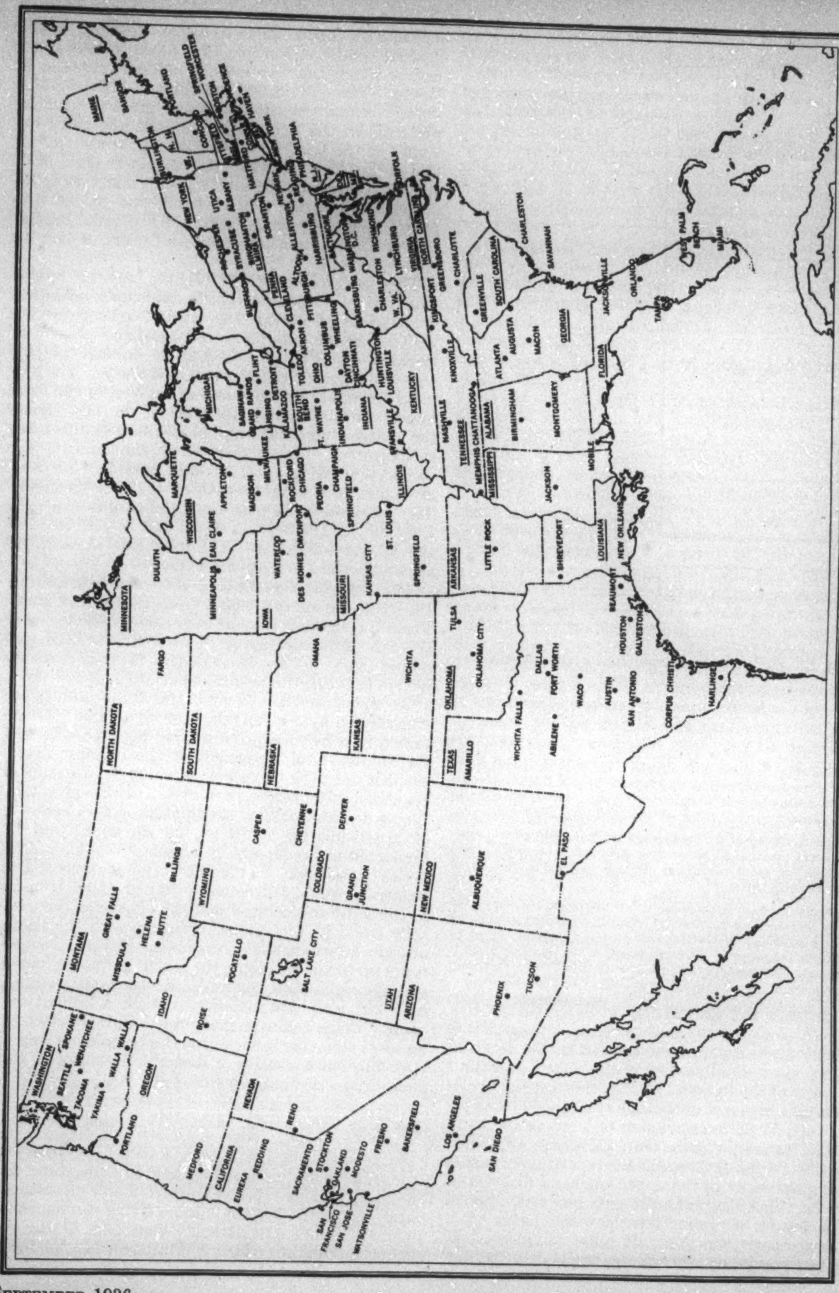

WASHINGTON
SEATTLE
TACOMA
YAKIMA
SPOKANE
WENATCHEE
WALLA WALLA
OREGON
PORTLAND
MEDFORD
CALIFORNIA
EUREKA
REDDING
SACRAMENTO
STOCKTON
OAKLAND
SAN FRANCISCO
SAN JOSE
WATSONVILLE
MODESTO
FRESNO
BAKERSFIELD
LOS ANGELES
SAN DIEGO
NEVADA
RENO
IDAHO
BOISE
POCATELLO
MONTANA
MISSOULA
GREAT FALLS
HELENA
BUTTE
BILLINGS
UTAH
SALT LAKE CITY
ARIZONA
PHOENIX
TUCSON
WYOMING
CASPER
CHEYENNE
COLORADO
DENVER
GRAND JUNCTION
NEW MEXICO
ALBUQUERQUE
EL PASO
NORTH DAKOTA
FARGO
SOUTH DAKOTA
NEBRASKA
OMAHA
KANSAS
WICHITA
OKLAHOMA
TULSA
OKLAHOMA CITY
TEXAS
AMARILLO
WICHITA FALLS
ABILENE
DALLAS
FORT WORTH
WACO
AUSTIN
SAN ANTONIO
HOUSTON
GALVESTON
BEAUMONT
CORPUS CHRISTI
HARLINGEN
MINNESOTA
DULUTH
MINNEAPOLIS
IOWA
WATERLOO
DES MOINES
DAVENPORT
MISSOURI
KANSAS CITY
ST. LOUIS
SPRINGFIELD
ARKANSAS
LITTLE ROCK
LOUISIANA
SHREVEPORT
NEW ORLEANS
WISCONSIN
EAU CLAIRE
MARQUETTE
APPLETON
MADISON
MILWAUKEE
ILLINOIS
ROCKFORD
CHICAGO
PEORIA
CHAMPAIGN
SPRINGFIELD
MISSISSIPPI
JACKSON
MOBILE
TENNESSEE
MEMPHIS
NASHVILLE
CHATTANOOGA
KNOXVILLE
KINGSPORT
ALABAMA
BIRMINGHAM
MONTGOMERY
GEORGIA
ATLANTA
AUGUSTA
MACON
SAVANNAH
FLORIDA
JACKSONVILLE
ORLANDO
TAMPA
WEST PALM BEACH
MIAMI
SOUTH CAROLINA
GREENVILLE
CHARLESTON
NORTH CAROLINA
CHARLOTTE
GREENSBORO
VIRGINIA
LYNCHBURG
RICHMOND
NORFOLK
KENTUCKY
LOUISVILLE
EVANSVILLE
INDIANA
INDIANAPOLIS
FT. WAYNE
SOUTH BEND
MICHIGAN
KALAMAZOO
LANSING
GRAND RAPIDS
SAGINAW
FLINT
DETROIT
OHIO
TOLEDO
CLEVELAND
AKRON
COLUMBUS
DAYTON
CINCINNATI
HUNTINGTON
W. VA.
CHARLESTON
CLARKSBURG
WHEELING
PENNA.
PITTSBURGH
ALTOONA
HARRISBURG
ALLENTOWN
READING
PHILADELPHIA
SCRANTON
WASHINGTON D.C.
BALTIMORE
N.J.
NEWARK
NEW YORK
BUFFALO
ROCHESTER
SYRACUSE
BINGHAMTON
ELMIRA
UTICA
ALBANY
VT.
BURLINGTON
N.H.
CONCORD
PITTSFIELD
HARTFORD
NEW HAVEN
SPRINGFIELD
WORCESTER
BOSTON
PROVIDENCE
PORTLAND
MAINE
BANGOR

Fig. 1. Map showing teletypewriter exchange service switching centers in the United States on April 1, 1936

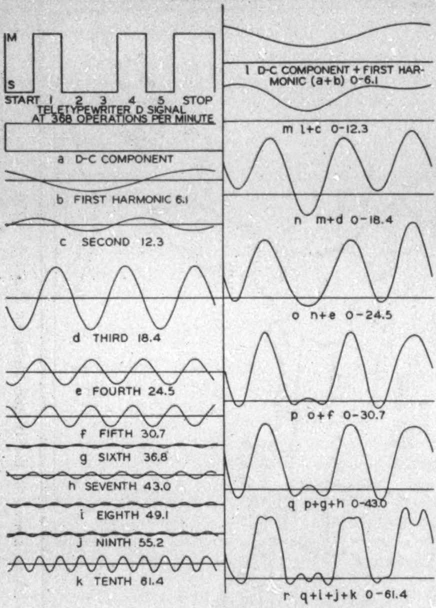


Fig. 2. Analysis of components of a teletypewriter "D" signal

Numbers on harmonic curves are frequencies in cycles per second

transmission as the result of changes in magnitude and phase of the various components caused by the characteristics of the transmission channel, so that changes in line condition at the receiving end will be gradual and in general displaced from their proper position.

4. Theoretically all of the intelligence can be carried by transmitting waves of a maximum frequency equal to that of the fundamental of the signaling speed considering the time interval of each signal element as a half cycle.

5. Actually it is not economical either to transmit a very wide band of frequency or to provide terminal apparatus capable of accurately recording the intelligence when only a band equal in width to the frequency of the fundamental of the signaling speed is transmitted. The arrangement used in practice must, therefore, be a compromise between these 2 extremes.

Experience has shown that in order to use economically practical types of receiving apparatus it is generally necessary to have present in the received signals a substantial portion of the second and third harmonics of the frequency of the shortest signal element, which requires in the case of 60-speed teletypewriter signals the transmission of a frequency band width of somewhat more than 45 cycles. To illustrate this a typical 60-speed teletypewriter signal is shown graphically in the upper left-hand diagram of figure 2. This diagram represents potential applied to the line for a perfect teletypewriter letter "D." At the instant when the start pulse commences, as described previously, the voltage applied to the line assumes its "open" value *S*, called "spacing." This spacing condition continues for 0.022 second at the end of which time the voltage suddenly assumes its "closed" value *M*, called "marking." The marking voltage remains constant through the first signaling pulse (1) in the figure. The second and third elements of the teletypewriter "D" signal are spacing and during these intervals the current is again of its spacing value. In the fourth pulse it once more becomes marking for 0.022 second, and in the fifth pulse it is again spacing. After the fifth pulse the current assumes its marking value for the duration of the stop signal.

This teletypewriter "D" signal may be further analyzed by considering it to be made up of sine wave components of various frequencies and magnitudes with certain definite phase relationships. It will be found theoretically to contain a number of sine waves of frequencies from zero to infinity. The left-hand column of figure 2 shows a number of the more important harmonic components of the "D" signal, the relative magnitudes and phase relationships being as indicated. The first is the d-c component; the second is a sine wave of the same period as the over-all signal, and is referred to as the first harmonic. The wave shown in part *c* of the figure is twice the frequency of the over-all signal and is referred to as the second harmonic. Following this in turn are shown the third to tenth harmonics.

The right-hand portion of the same figure shows the synthesis of this signal from component parts. From this figure it may be seen that by the time the seventh harmonic (curve *q*) or even the fifth harmonic (curve *p*) has been added, there is a resemblance between the resultant and the original wave.

As mentioned previously, the total intelligence transmitted by a given telegraph signal may be contained in a frequency band lying between zero and the fundamental frequency of the shortest signal element, i. e., the frequency at which the duration of the shortest element is a half cycle. In 60-speed teletypewriter transmission the shortest signal element is of approximately 0.022 second duration, and its fundamental frequency is about 1/0.044 = 22.7 cycles per second. In the illustration in figure 2, this frequency would fall between that of curves *d* and *e* in the left-hand column and the character theoretically could be interpreted correctly with the transmission incorrect phase relation of only the components up to and including the fourth harmonic (curve *o* in the right-hand column). As previously stated, however, while transmission of such a limited frequency range could be interpreted without error by an ideal receiving device, practical considerations of over-all economy make it desirable to transmit the wider frequency range mentioned.

Types of Distortion

In order to design a satisfactory teletypewriter transmission system it is desirable to understand the effects of various types of distortion and mechanical variations in the sending and receiving mechanisms. Figure 3 shows schematically that part of the receiving mechanism which is of interest in explaining the effect of signal distortion on correct interpretation of the message. This includes a receiving selector magnet with its associated armature and armature extension, a locking lever, a stop latch, and a selector cam driven by a friction clutch. In the idle condition the selector magnet is energized and the magnet armature and armature extension are in the position shown, the selector cam being held from rotating by the stop latch. When a train of impulses representing a character is received the start pulse (spacing) allows the armature and armature extension to move to a position shown by the dotted lines and at the same time releases the stop latch. This latter operation permits the selector cam to start rotating. The speed of rotation and the starting position of the selector cam are normally so adjusted that the first depression (shown by A) will arrive at the locking lever at the time the middle of the first selecting impulse is being received. The locking lever will then fall into this depression and the locking wedge B will move toward the armature extension and lock it in the position it occupies at this instant. This determines which of the 2 line conditions will be recorded for this signal element. Immediately thereafter mechanical arrangements (not shown) will operate to transfer this information to the selection storing mechanism. This process will then be repeated for each of the other 4 selecting impulses.

After the 5 selecting impulses have been received the slightly longer stop impulse is received. During the latter part of this impulse an arm C on the receiving selector cam will strike the stop latch and the cam will be held until the reception of the start impulse for the next character.

An orientation device or range finder is provided which rotates the stop latch with respect to the locking lever and thereby changes the time at which selection occurs with respect to the beginning of the selecting cycle. Moving the orientation range finder in effect moves the solid vertical lines in figure 3, with respect to the signal, and with perfect signals they can be moved by an amount corresponding to one unit impulse. In other words the time of selection can be moved by ± 50 per cent without typing errors, as shown at *a* in the figure. (In an actual machine this range is less because of practical considerations of design, the time of selection being variable without errors over a range of about ± 40 per cent.)

Distortion in teletypewriter signals may be "bias," which is a uniform lengthening or shortening of all the marking impulses, or it may be of other types which affect only certain of the signal elements.[4] Bias is divided about equally between the ends of the impulse when the signal is received from the line. However, because the selecting mechanism starts rotating at the beginning of the start impulse, the effect of bias is to shift all impulses forward or backward with respect to this time. The result of this is that effectively there will be an addition to or subtraction from the front of each marking impulse, with the rear of the impulses remaining unchanged.

In an ideal machine where selection would be made instantaneously the signal would be recorded correctly if it had the right condition (i. e., marking if it should be marking or *vice versa*) at the instant of selection. The particular times when the selections take place with the orientation setting at the middle of the range with perfect signals are shown, as mentioned before, by the vertical solid lines numbered 1 to 5, inclusive, in figure 3. Referring to cases *b* and *d* it may be seen that with 25 per cent bias the correct signal is being received at the point of selection and it will be interpreted correctly. However, referring to cases *c* and *e* it may be seen that more than 50 per cent bias will cause errors. In case *c* the second and fifth impulses will be falsely interpreted as marking and in case *e* the first and third impulses will be spacing instead of marking. Several examples of the effect of distortion other than bias in the received signals are illustrated in cases, *f*, *g*, and *h* of figure 3.

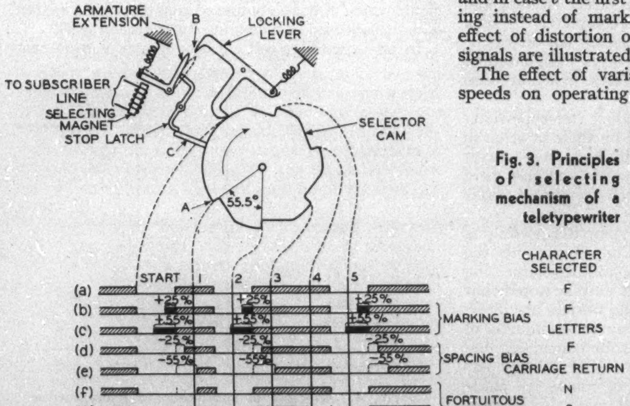


Fig. 3. Principles of selecting mechanism of a teletypewriter

The effect of variations in teletypewriter motor speeds on operating margins is illustrated in the adjoining figure 3 by cases *i* and *j*. Case *i* shows the result if the sending machine is faster than the receiving machine. It will be noted that as the speed discrepancy becomes greater the first error will be a false mark for the fifth impulse because a part of the stop impulse is received on the fifth position. If perfect signals are assumed, the speeds would have to be somewhat more than 7 per cent different to cause errors of this kind in a normal teletypewriter with the range finder set in the middle of the range, but if there is some signal distortion other than that from speed discrepancies, such as marking bias, smaller differences in speed would be sufficient to cause errors. Case *j* illustrates the conditions when the sending distributor is slower than the receiving distributor. It will be observed in this case that the first error as the speed discrepancy increased would also be in the fifth impulse as the result of either the fourth impulse being sufficiently prolonged to fall on the fifth selecting position, or the fifth impulse being so late in starting that it is not properly received on the fifth position.

In the illustrations large speed discrepancies have been used so that the shift of the signals could be shown readily on a drawing.

GENERAL TRANSMISSION DESIGN OF *TWX* NETWORK

Telegraph circuits comprising the transmission network employed in teletypewriter exchange service are laid out according to a fundamental plan similar to the toll switching plan[5] used in designing the toll telephone plant. The teletypewriter switching plan is designed to provide on the most economical basis the circuits necessary for satisfactory connection between any 2 stations in the country without any special line-up or adjustment of the circuits or apparatus.

Each switching point has a direct connection to each of the subscriber stations within its area (except for a few stations which are connected to the switchboards by a single channel carrier circuit operating over regular toll telephone circuits when a connection to these stations is desired.) In addition it has direct toll circuits to one or more of the other switching points. Eight cities of considerable importance from the standpoint of switching in the national network are designated as "regional centers." These cities, New York, Atlanta, Chicago, St. Louis, Dallas, Denver, San Francisco, and Los Angeles, are interconnected largely by high grade direct circuits and ultimately will be interconnected completely by such facilities. Each of the regional centers has direct circuits to a number of smaller centers designated as "routing outlets" within a given area, which are also interconnected by direct circuits.

The other switching centers, called "teletypewriter centers," which are not required by their position in the networks to handle through business, have direct circuits to one or more routing outlets and may have direct connections to similar nearby centers if traffic justifies it.

The application of the teletypewriter switching plan is illustrated in figure 4. Considering only the toll circuits of the basic routes (solid lines connecting switching centers in the figure), it may be noted that within any area where the routing outlets are interconnected by direct circuits, the maximum number of teletypewriter toll lines required for connection between 2 stations in the area is 3. A very large percentage of the connections can, of course, be made with only one or 2 toll links. It may also be seen that, assuming all regional centers to be interconnected by direct circuits, a maximum of 5 toll links will serve to connect any 2 stations in the country, using only the basic routes.

In addition to these basic toll routes, supplementary routes are provided wherever the traffic warrants, as indicated by the dashed lines in the figure. These supplementary routes may be direct circuits between 2 teletypewriter centers, between a teletypewriter center and a routing outlet or regional center other than that through which it is normally served, or between a routing outlet in one area and a routing outlet or regional center in another regional area. It is obvious from the figure that the effect of these supplementary routes is to reduce the number of toll links and consequently the number of switches involved in certain connections.

The plan permits considerable flexibility with respect to arrangements for future expansion and changes, as growth can be taken care of by the provision of additional switching points or additional direct circuits with practically no change in the fundamental framework.

TRANSMISSION REQUIREMENTS

In the consideration of the transmission requirements the following items are of importance:

1. The over-all distortion on all connections must be low enough to permit satisfactory service.

2. The distortion on all of the links which will at times be part of built-up connections must be sufficiently low to permit satisfactory transmission when forming a part of such connections.

3. The distribution of distortion between the various toll links and between those links and the subscriber lines should be such as to obtain the desired transmission results with a minimum cost for the plant as a whole.

TRANSMISSION COEFFICIENTS

The transmission requirements of the over-all connection or of the individual elements are expressed in terms of a system of telegraph transmission coefficients which may be compared roughly to the system of net losses used in telephone transmission work.

In teletypewriter toll circuits of one or more sec-

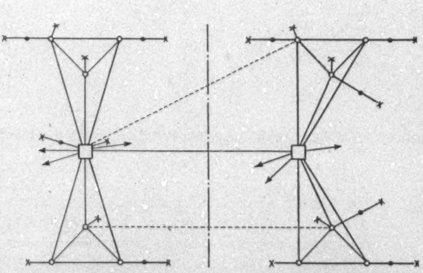


Fig. 4. Principle of application of teletypewriter switching plan

□ Regional center
○ Routing outlet
● Teletype center
× Subscriber station
— Basic routes
--- Supplementary routes
→ Routes to other regional centers

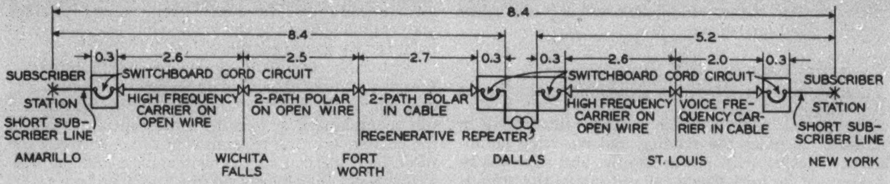


Fig. 5. Diagram of typical teletypewriter exchange service connection requiring regenerative repeater

Numbers are transmission coefficients

tions the over-all distortion is made up of increments from a number of sources. Experience has shown that in general the over-all distortion of a particular signal element is equal to the algebraic sum of the individual increments. For each specific piece of equipment or element of the circuit the sign and value of the distortion cannot be predicted exactly as they depend upon facts which vary with individual cases. However, representative values of the maximum distortion experienced in a period of moderate length with miscellaneous signals for different types of circuit and equipment may be determined with fair accuracy. Experience and probability theory indicate that the most probable value of the over-all distortion of a telegraph circuit may be computed by taking the square root of the sum of the squares of the corresponding values for the various component parts of the circuit. With this as a basis coefficients have been established for individual telegraph circuits of the various types employed in the *TWX* transmission system. These coefficients are, in general, proportional to the square of the maximum distortion experienced with severe signal combinations under comparatively unfavorable conditions of circuit adjustment, weather conditions, etc., taking into account what is known about the general stability of the particular facility concerned. An estimate may then be made of the transmission impairment to be expected in service with a teletypewriter circuit made up of a number of sections of various types by adding the coefficients of the component parts. For convenience the value of the coefficients has been so chosen that satisfactory operation normally will be obtained over a connection if the sum of the transmission coefficients for the subscriber lines, switchboard circuits, and toll lines involved does not exceed 10.

Using these coefficients the entire transmission system is designed to provide satisfactory transmission between any 2 subscribers or combinations of subscribers. It is found that subscriber lines less than about 5 miles in length contribute little or no distortion to the over-all connections. Those up to about 35 miles may contribute distortion so as to warrant allowing a coefficient as high as 1.0 or 1.5, and for those up to 50 or 60 miles the coefficient may be as great as 3.5 or 4.0.

The following discussion assumes that the subscriber lines have a coefficient of not more than 1.0 or 1.5 from the subscriber station to the jack connected to the teletypewriter toll line at the switchboard, leaving for the toll links of the connection a maximum coefficient of about 7.0 or 8.0. In the case of intra-area connections involving 3 toll links, a permissible coefficient of 8.0 for all the links of the connections would, of course, permit a coefficient of about 2.7 for each link. Correspondingly, a connection involving 5 links would permit a coefficient of only 1.6 per link. It happens, however, that the transmission capabilities of the teletypewriter circuits generally in use are such that none of the circuits has a coefficient of less than 2.0 and that single sections of circuit may lie in the range of about 2.0 to 5.0. Practically, the availability of the higher grade circuits is limited by reasons of economy since, for example, the multichannel carrier telegraph facilities which have coefficients of 2.0 to 2.6 would be too expensive to use for routes where only a few circuits are required or for the shorter links. It is apparent, therefore, that an over-all coefficient of 7.0 to 8.0 cannot be realized on either 4 or 5 link connections without some means for overcoming the over-all distortion. For these cases the operators are provided with connections to regenerative repeaters, which are inserted in series with the circuit and retransmit the teletypewriter signals exactly as they were originally transmitted into the circuit at the sending end, provided they have not been distorted beyond the point where they can be correctly interpreted by the regenerative repeater. The latter has about the same signal distortion tolerance that a teletypewriter would have if the circuit terminated at that point. Thus the regenerative repeater wipes out the distortion of the preceding toll links and subscriber line so that the coefficient at its output will again be zero. The circuit layout for an actual connection is shown in figure 5 illustrating the use of a regenerative repeater.

For the purpose of the teletypewriter exchange circuit layout, it is assumed that regenerative repeaters are available at the switchboards of all regional centers so they may be used to handle 4 and 5 link connections. They are required occasionally at routing outlets to provide satisfactory over-all results on 3 link connections. In the case of 2 link connections the use of regenerative repeaters is ordinarily avoided by limiting the coefficient of the subscriber line, switchboard, and first toll circuit to 5.0. For subscriber lines on which it is not economical to provide facilities having coefficients as low as 1.5 the traffic routing instructions call for the use of additional regenerative repeaters at suitable points.

The types of telegraph facilities that are used for these various classes of toll link and subscriber line are discussed farther on.

FACILITIES USED IN *TWX* NETWORK—TELETYPEWRITER STATIONS AND SUBSCRIBER LINES

A typical teletypewriter station, illustrated in figure 6, includes the sending and receiving equipment, together with power supply, and supervisory equipment for initiating a call, informing the attendant of an incoming call, or recalling the switchboard operator during the progress of a connection if desired. These features are described in detail in the paper on switchboards and signaling facilities referred to previously.[1]

Any one of several types of teletypewriter subscriber lines may be used to connect a station with the switchboard from which it is served, the type chosen depending upon conditions in the particular case. A large majority of subscriber lines, however, consist of cable pairs used exclusively for that purpose. In these the telegraph method employed is one in which polar signals (a positive potential for spacing and a negative potential for marking pulses or *vice versa*) are impressed on the subscriber line by a telegraph repeater in the cord circuit at the central office, and neutral signals (the circuit closed for marking and opened for spacing) are transmitted by the sending contacts of the teletypewriter at the subscriber station.

The polar signals transmitted from the central office are symmetrical and the transmission quality of these signals is not affected seriously by the capacitance of the cable loop. As is ordinarily the case in duplex transmission, the current impulses are transmitted differentially through 2 windings of a relay in the cord circuit repeater which responds to incoming signals but not to the outgoing differentially transmitted signals. To prevent the undesired response of this relay to the outgoing signals, it is necessary that the differential winding not connected to the subscriber line be terminated to ground through an impedance similar to that of the subscriber line. Since subscriber lines from a given type of switchboard are all arranged to use the same current value the resistance component of the station line impedance may be balanced by fixed resistance.

Fig. 6. Typical teletypewriter subscriber station

With cable circuits of appreciable length, however, the capacitance becomes of importance. Up to a certain length the effect of the capacitance on balance can be minimized by locating a substantial portion of the current limiting resistance in series between the subscriber line jack at the switchboard and the subscriber line. For longer circuits an impedance modifying network consisting of capacitance, inductance, and resistance in parallel is inserted in series with the circuit between the subscriber line jack and the subscriber line. The constants of this network are so chosen that the subscriber line will be satisfactorily balanced by the same cord circuit repeater balancing arrangement that is used for the shorter subscriber lines in the office.

At the station the sending contacts and receiving relay or magnet are in series with the subscriber line. Signals from subscriber stations are formed simply by opening and closing the circuit at the sending contacts in accordance with the code for the characters being transmitted. When the contacts are closed a current flows in the subscriber line circuit for marking and when they are open this current becomes zero, transmitting a spacing signal.

On long cable pair subscriber line circuits with considerable bridged capacity, the wave shape of the current received in the central office is not symmetrical as regards the marking or spacing conditions, the rate of building up of the marking current being much faster than its rate of decay. This results in marking bias in the received signals. Conversely, in subscriber line circuits containing only series inductance and resistance, the received current builds up gradually to its marking value and decays to zero immediately when the sending contacts are opened for a space. By properly combining the inductance and capacitance, it is possible to produce substantially unbiased signals at the receiving end. In other words, by inserting series inductance in a cable circuit, it is possible to overcome the marking bias effect mentioned above so that practically no distortion occurs in the subscriber line.

The marking bias may also be reduced effectively by the use of series resistance in place of inductance at the subscriber station in cases where it is possible to aid a sufficient amount of resistance without reducing the current below the desired value. The effect of series resistance used in this way is to delay the building up of the current when the teletypewriter sending contacts are closed after a spacing signal to compensate for the delay in decay of the received current after the contacts have opened.

Both of the above methods of reducing bias are in use in the present teletypewriter exchange plant. Figure 7 shows the wave shape of uniformly timed marks and spaces received over a 30-mile 19-gauge cable pair, illustrating the effect of the cable capacitance, and the manner in which a wave shaping arrangement, consisting primarily of inductance in this case, reduces the amount of marking bias in the received signal by retarding the building up of current at the start of each marking signal.

Although the majority of subscriber lines are in cables, it is sometimes necessary to serve stations at greater distances from the teletypewriter center or in situations where the use of cable pairs is not practicable. For these other arrangements must be made. One method of serving such stations is by means of arrangements similar to those of the shorter toll circuits. Generally a telegraph repeater in an office in the vicinity of the subscriber station is used, and transmission between that repeater and the one in the teletypewriter center takes place in the same manner as over a toll circuit of similar length.

Another method for connecting to subscriber stations which cannot be cared for by a metallic cable pair employs a simple telegraph repeater installed as part of the subscriber station equipment. This arrangement as well as the one previously described has the advantage that it permits polar signals to be used in both directions over the subscriber line.

In a few cases which have arisen where telegraph facilities were not readily available between the teletypewriter center and a subscriber station, use has been made of a single channel voice frequency carrier telegraph arrangement by means of which the transmission takes place over standard telephone circuits. A small carrier telegraph terminal arrangement is mounted on the back of the teletypewriter table, and a corresponding carrier terminal is located in the teletypewriter center in a trunk circuit between the teletypewriter switchboard and the telephone toll board. Special operating procedures are set up so that whenever the subscriber initiates a call, connection is established by telephone operators over telephone circuits to the above mentioned carrier trunk circuit at the teletypewriter center, and the teletypewriter switchboard operator is notified of the call and given the number of the subscriber by whom it is made. From the subscriber's standpoint calls are made with this equipment in practically the same manner as when ordinary telegraph facilities are employed.

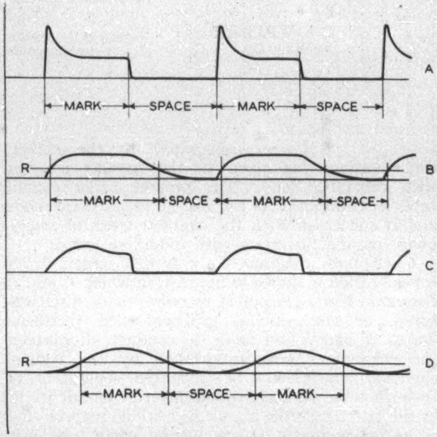


Fig. 7. Effect of wave shaping networks in long subscriber lines operated over cable pairs

A—Current at subscriber station; no wave shaping network used

B—Current in A as received at central office

C—Current at subscriber station; loop equipped with wave shaping network

D—Current received at central office; loop equipped with wave shaping network

R—Current required to operate receiving relay of repeater in central office

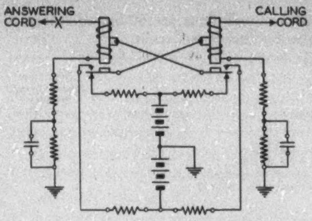


Fig. 8. Principle of switchboard transmission circuit

Operator's teletypewriter inserted at X when required

SWITCHBOARDS

The switchboards used in teletypewriter exchange service contain facilities for interconnecting subscriber lines, connecting them with toll circuits, or interconnecting toll circuits as required, together with the necessary means for establishing and supervising the connections. They are described in considerable detail in the previously referred to paper on switchboards and signaling facilities.[1] As indicated in the discussion of subscriber lines, the transmission circuit through the switchboard is essentially a differential duplex telegraph repeater. One such repeater is connected between the cords of each pair. This repeater is do designed that it introduces very little distortion in the connection. The coefficient of the switchboard cord circuit is 0.3. Figure 8 is a schematic diagram showing the principle of the transmission circuit.

TOLL CIRCUITS

The toll circuits of the teletypewriter exchange network are of the standard types that are in general use for telegraph transmission. These include voice frequency carrier telegraph systems on cable circuits[6] or on channels of carrier telephone circuits on open wire lines, high frequency carrier telegraph systems on open wires,[7] metallic systems on cables,[8] and 2 path polar and differential-duplex grounded telegraph circuits.[9] An idea of the relative capabilities of these types of facilities may be obtained from table I which shows the coefficients of a single section of each type.

From the coefficients given in the table and the earlier discussion of the teletypewriter switching plan, it is apparent that the carrier systems, voice frequency or high frequency, where available, are

Table I—Transmission Coefficients for 60-Speed Teletypewriter Exchange Circuits

Type of Circuit	Coefficient per Section*	Maximum Section Length Normally Used, Miles
D-c grounded system on open wire	2.5 to 4	300
D-c metallic system on cable circuits	2 to 3	150
High frequency carrier system on open wire	2.6	1,150
Voice frequency carrier system on cable or open wire circuits	2.0 to 2.2	3,500

* The term "section" as here used designates the part of a telegraph circuit between 2 telegraph repeaters or a section of a telegraph circuit without any intermediate telegraph repeaters. For example, a telegraph repeater section operated by the voice-frequency carrier telegraph method is that part of the circuit between carrier telegraph terminal sets, regardless of the number of intermediate telephone repeaters in the carrier circuit.

most suitable for the longer backbone toll circuits of the nationwide network. For the short circuits of from 100 to 200 miles where cable plant is available, the metallic telegraph circuits on cable are extensively used, while for the scattering circuits of similar length, and most of the shorter toll circuits, use is made of 2 path polar and differential duplex facilities. In some instances where single section facilities of the required grade are not available between 2 centers, regenerative repeaters permanently associated with multisection circuits are used to provide satisfactory over-all circuits. Also in certain instances where circuits are not required for through switching, multisection circuits without regenerative repeaters are sometimes provided and classified "for terminal purposes only."

All the components of the network—teletypewriters and their associated subscriber lines, transmission circuits in the switchboards, and toll circuits interconnecting the switchboards—are designed to give a satisfactory over-all transmission performance with a minimum cost for the plant as a whole. Results obtained in service indicate that the system is meeting a commercial need and that its performance is satisfactory, but developments are continually under way to effect further improvements in service and economies in operation as experience is gained with the system.

REFERENCES

1. Switchboard and Signaling Facilities of the Teletypewriter Exchange System, A. D. Knowlton, G. A. Locke, and F. J. Singer. (A paper scheduled for early publication in Electrical Engineering.)

2. Certain Topics in Telegraph Transmission Theory, H. Nyquist. A.I.E.E. Trans., v. 47, 1928, p. 617–44.

3. Certain Factors Affecting Telegraph Speed, H. Nyquist. A.I.E.E. Jl., v. 43, February 1924, p. 124–30.

4. Measurement of Telegraph Transmission, H. Nyquist, R. B. Shanck, and S. I. Cory. A.I.E.E. Jl., v. 46, March 1927, p. 231–40.

5. General Switching Plan for Telephone Toll Service, H. S. Osborne, A.I.E.E. Trans., v. 49, 1930, p. 1549–57.

6. Voice Frequency Carrier Telegraph System for Cables, B. P. Hamilton, H. Nyquist, M. B. Long, and W. A. Phelps. A.I.E.E. Jl., v. 44, March 1925, p. 213–18.

7. Carrier Current Telephony and Telegraphy, E. H. Colpitts and O. B. Blackwell. A.I.E.E. Jl., v. 40, 1921, April, p. 301–15, May, p. 410–21, and June, p. 517–26.

8. Metallic Polar-Duplex Telegraph System for Cables, John H. Bell, R. B. Shanck, and D. E. Branson. A.I.E.E. Trans., v. 44, 1925, p. 316–25.

9. Modern Practices in Private Wire Telegraph Service, R. E. Pierce. A.I.E.E. Trans., v. 50, 1931, p. 426–35.

Parallel Inverter With Inductive Load

Calculation of the characteristics of a single phase parallel inverter supplying an inductive load is treated in this paper, which supplements a previous paper on the parallel inverter supplying a pure resistance load. The treatment is confined to the case in which the direct current is constant, no attempt being made to derive expressions for the case in which the direct current flows in pulses.

By
C. F. WAGNER
MEMBER A.I.E.E.

Westinghouse Elec. and Mfg. Co., East Pittsburgh, Pa.

IN a previous paper[1] by the author, consideration was given to the parallel inverter with resistance load. The present paper constitutes a continuation of the subject of static inverters and is concerned with the characteristics of single-phase parallel inverters with inductive loads.

A schematic diagram of the type of circuit under consideration is shown in figure 4, in which A and B designate 2 grid-controlled mercury-vapor discharge tubes, or conventional grid-controlled rectifiers. Tubes A and B are made to conduct alternately, the frequency being established by the control elements which may be inititated separately or through some function of the inverter circuit itself; in the latter case the circuit as a whole may be said to be self-excited. At any instant when tube A is conducting, current flows from the source of continuous voltage, E, through the ballast inductance L_1, half the primary winding of the transformer, and the tube. If now tube B is made conducting, the commutating capacitor C tends to discharge through the 2 tubes and in the process extinguishes the current in A, thus transferring or commutating the current to tube B. As tube A is made conducting again, a similar process occurs in which the current in tube B is commutated. An alternating current thus is induced in the secondary of the transformer and through the load consisting of the resistance R and the inductance L. To supplement the foregoing somewhat brief description of operation, the varia-

---

A paper recommended for publication by the A.I.E.E. committee on electrophysics. Manuscript submitted January 21, 1936; released for publication March 19, 1936.

[1] For all numbered references see list at end of paper.

tions of the currents and voltages at different points in the circuit are shown in figure 1.

MODES OF OPERATION

In general, 2 distinct modes of operation are recognizable. These 2 modes are dependent upon the relative values of the circuit constants and arise from the physical limitation of the tubes which permits current conduction in one direction only. Under certain circumstances, the current in the d-c side of the inverter flows in pulses, 2 for each cycle of control frequency, with periods of current zero intervening. Under other circumstances, the current in the d-c side is continuous without reaching zero. The calculation of currents and voltages for the former case is much more involved than that for the latter. However, it so happens that the most important case for which the current flows in pulses is that in which the periods of current zero approach zero. But this may be regarded also as a limiting case for which the current on the d-c side is continuous. No attempt will be made, therefore, to derive expressions for the case in which the direct current flows in pulses.

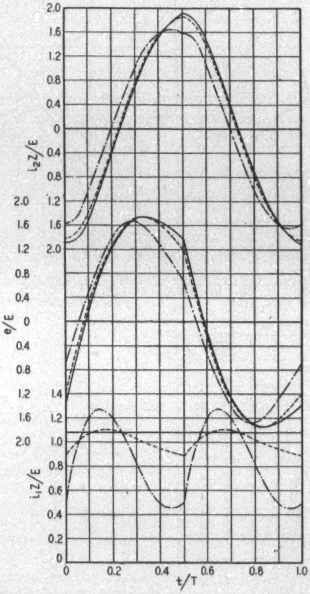


Fig. 1. Effect of different values of X_1 on i_2, i_1, and e for PF = 0.6 and K = 1.2

—— $X_1/Z_2 = \infty$
---- $X_1/Z_3 = 5$
- - - $X_1/Z_3 = 1$

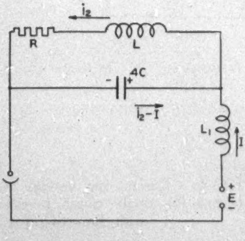


Fig. 2. Equivalent circuit for inverter

In the appendix may be found the development of a method for calculating the general case for which the direct current is continuous. However, the most important case to consider is that in which the current in the d-c side is constant, that is, the inductance in the d-c side is infinitely large. This case will be developed in the body of the paper. A method also will be given to estimate the variation in the direct current for cases in which these variations are small.

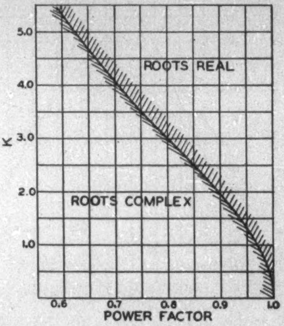


Fig. 3. Curve showing effect of constants upon nature of solution

CONSTANT DIRECT CURRENT

In the following development, these simplifications are made:

1. The magnetizing current and the leakage reactances of the transformer are neglected.

2. All 3 windings have the same number of turns. If this is not the case, the load impedances can be reduced readily to an equivalent impedance.

3. The resistance of the inductance in the d-c side is neglected. This can be corrected for by subtracting a constant voltage drop from the applied continuous voltage.

4. The voltage drop in the tubes is neglected. Since this is essentially constant regardless of current, it can be corrected for by subtracting the drop from the applied voltage.

The circuit under consideration is shown schematically in figure 4, in which the symbols are self-explanatory. Part or all of the capacitor C may be connected in parallel with the load. It may be desirable also that some of the capacitance be switched on simultaneously with the load.

The general plan of attack will be to set up the differential equation for that portion of the circuit involved while one tube is conducting and the other tube is open-circuited. Because of certain symmetry in the circuit, definite terminal conditions may be set up. Thus, the load current at the beginning of a half period must be equal and opposite to the load current at the end of the half period. Similarly, the charge q on the commutating capacitor at the beginning of a half period must be equal and opposite to the charge at the end of the half period. Calling the period T, these relations may be expressed by the following:

$$i_2 \text{ (for } t = 0) = -i_2 \text{ (for } t = T/2) \tag{1}$$

$$q \text{ (for } t = 0) = -q \text{ (for } t = T/2) \tag{2}$$

The foregoing assumptions permit the elimination of the transformer for the purpose of setting up the

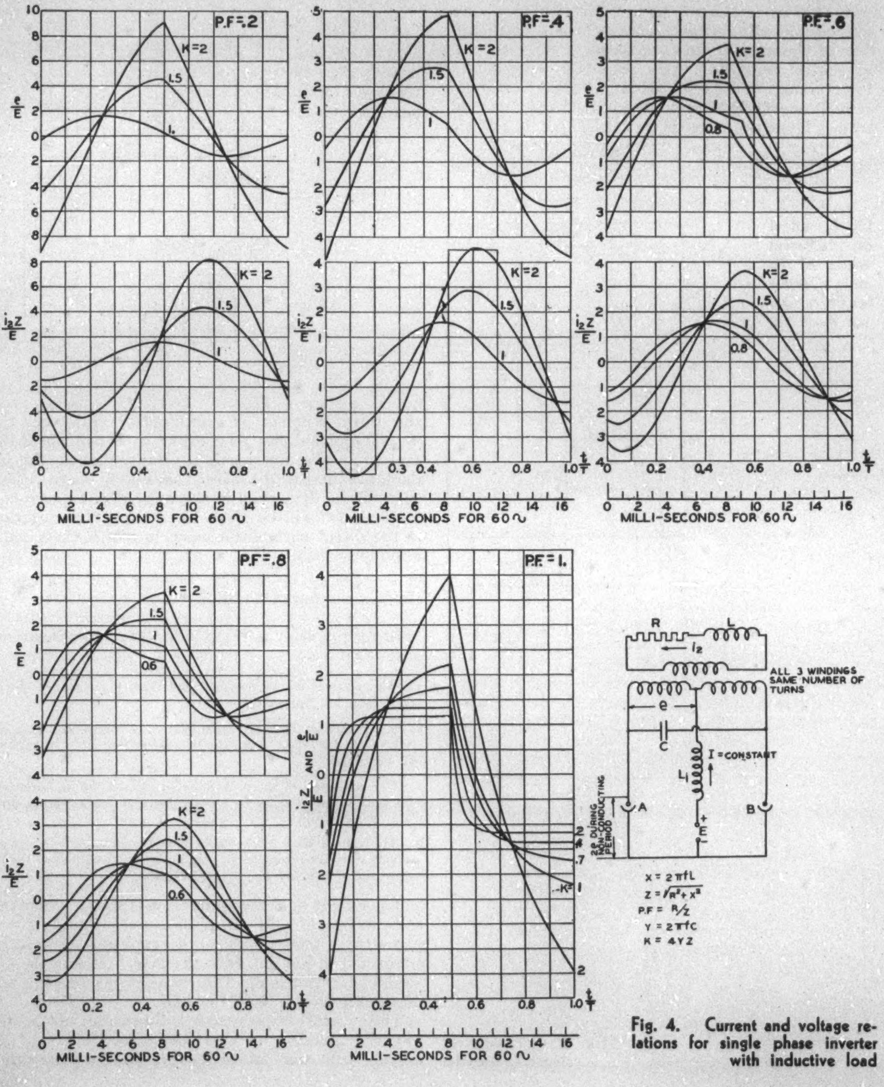


Fig. 4. Current and voltage relations for single phase inverter with inductive load

differential equation, thus reducing the equivalent circuit to that shown in figure 2. The constant current I in the d-c side will be evaluated in terms of the voltage E and the constants of the circuit. The charge on the capacitor $4C$ is designated by the symbol q.

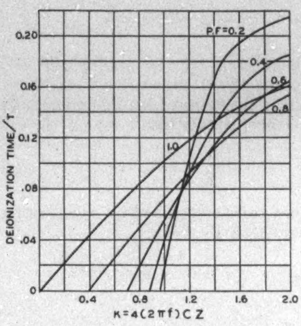


Fig. 5. Curves for deionization time

For the circuit consisting of R, L, and $4C$, the voltage equation may be written:

$$Ri_2 + \frac{X}{\omega}\frac{di_2}{dt} - \frac{\omega q}{4Y} = 0 \tag{3}$$

in which X and Y are the reactance and admittance at control frequency f of the inductor L and capacitor C, respectively, and ω is equal to $2\pi f$.

The charge on the capacitor is related to the current by

$$-\frac{dq}{dt} = i_2 - I \tag{4}$$

Substituting i_2 and $\frac{di_2}{dt}$ from equation 4 into equation 3, there results

$$\frac{X}{\omega}\frac{d^2q}{dt^2} + R\frac{dq}{dt} + \frac{\omega q}{4Y} = RI \tag{5}$$

Now let

$$q = Q\epsilon^{mt} \tag{6}$$

After substituting in the homogeneous equation 5, that is, the right hand member being let equal to zero, there results

$$\frac{X}{\omega}m^2 + Rm + \frac{\omega}{4Y} = 0 \tag{7}$$

The roots of this auxiliary equation give the values of m which when substituted in equation 6 provide the complementary function of equation 5. These roots are:

$$m = -\frac{\omega R}{2X} \pm \omega\sqrt{\frac{1}{4}\left(\frac{R}{X}\right)^2 - \frac{1}{4YR}\frac{R}{X}} \tag{8}$$

These may be either complex or real. In the former case the solution consists of damped sinusoids, but in the latter of exponentials.

ROOTS COMPLEX

For the case in which the roots are complex, let them be designated as

$$m = (-\alpha \pm j\beta)\omega \tag{9}$$

in which

$$\alpha = \frac{R}{2X} \tag{10}$$

$$\beta = \sqrt{\frac{1}{(4YR)}\left(\frac{R}{X}\right)}\ \sqrt{1 - \frac{1}{4}\left(\frac{R}{X}\right)(4YR)} \tag{11}$$

The complete solution of equation 5 may be written as

$$q = \text{real part } \boldsymbol{Q}\,\epsilon^{\omega(-\alpha+j\beta)t} + \frac{4RY}{\omega}I \tag{12}$$

in which the last term represents the particular integral.

From equations 4 and 12,

$$i_2 = I - \text{real part } \omega(-\alpha + j\beta)\,\boldsymbol{Q}\,\epsilon^{\omega(-\alpha+j\beta)t} \tag{13}$$

By applying the terminal conditions expressed by equations 1 and 2, the complex coefficient $\boldsymbol{Q}$ can be evaluated. Thus for the condition of equation 2,

$$\text{real part } \boldsymbol{Q} + \frac{4RY}{\omega}I = -\text{real part } \boldsymbol{Q}\epsilon^{(-\alpha+j\beta)\omega\frac{T}{2}} - \frac{4YR}{\omega}I$$

and since $2\pi fT/2 = \pi$

$$\text{real part } \boldsymbol{Q}\,[1 + \epsilon^{(-\alpha+j\beta)\pi}] = -\frac{8RYI}{\omega} \tag{14}$$

For the condition of equation 1,

$$I - \text{real part } \omega(-\alpha + j\beta)\boldsymbol{Q} = \\ -I + \text{real part } \omega(-\alpha + j\beta)\boldsymbol{Q}\epsilon^{(-\alpha+j\beta)\omega\frac{T}{2}}$$

or

$$\text{real part } \boldsymbol{Q}\,\omega(-\alpha + j\beta)[1 + \epsilon^{(-\alpha+j\beta)\pi}] = 2I \tag{15}$$

Now let

$$\boldsymbol{Q} = (A + jB)\frac{I}{f} \tag{16}$$

in which A and B are undetermined real coefficients. Also, let

$$[1 + \epsilon^{(-\alpha+j\beta)\pi}] = m + jn \tag{17}$$

Equation 14 becomes

$$\text{real part } (A + jB)\frac{I}{f}(m + jn) = -\frac{8RY}{2\pi f}I$$

or

$$mA - nB = -\frac{4RY}{\pi} \tag{18}$$

and equation 15 becomes

$$\text{real part } (A + jB)\frac{I}{f}2\pi f(-\alpha + j\beta)(m + jn) = 2I$$

or

$$(\alpha m + \beta n)\, A + (\beta m - \alpha n)\, B = -\frac{1}{\pi} \qquad (19)$$

Solving equations 18 and 19 simultaneously for A and B there results that

$$A = -\frac{(4RY)(\beta m - \alpha n) + n}{\pi\beta(m^2 + n^2)} \qquad (20)$$

$$B = \frac{-m + (4RY)(\alpha m + \beta n)}{\pi\beta(m^2 + n^2)} \qquad (21)$$

The voltage e across the capacitor is equal to the charge divided by the capacitance. Thus,

$$e = \frac{q}{4C} = \frac{\omega q}{4Y} = \frac{\omega}{4Y}\left[\text{real part } (A + jB)\frac{I}{f}\,\epsilon^{\omega(-\alpha + j\omega)t} + \frac{4RY}{\omega} I\right]$$

$$= \text{real part } \frac{\pi I}{2Y}(A + jB)\epsilon^{\omega(-\alpha + j\omega)t} + RI \qquad (22)$$

In what follows it will be found convenient to express the results, so far as possible, in terms of 2 dimensionless parameters, namely, $4YZ = K$, and PF. The former expresses approximately the ratio of the kilovolt-ampere capacity of the capacitors to the kilovolt-amperes of the load. The latter represents the power factor of the load as defined under the diagram in figure 4.

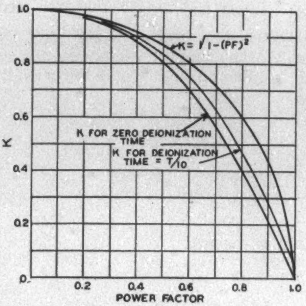


Fig. 6. Comparison of value of K for fixed deionization time with that to produce resonance

Inserting these parameters,

$$e = ZI\left[\text{real part } \frac{2\pi}{K}(A + jB)\epsilon^{\omega(-\alpha + j\beta)t} + PF\right]$$

$$= ZI\left[\frac{2\pi}{K}\,\epsilon^{-2\pi\alpha\frac{t}{T}}\left(A \cos 2\pi\beta\frac{t}{T} - B \sin 2\pi\beta\frac{t}{T}\right) + PF\right] \qquad (23)$$

There remains yet to evaluate I. Because, by assumption, the ballast inductance in the d-c side is resistanceless, then the average value of e must be equal to E. Integrating equation 23 between 0 and $T/2$, dividing by $T/2$, and equating to E, there results

$$ZI\left\{\frac{2}{K(\alpha^2 + \beta^2)}\left[\epsilon^{-\pi\alpha}\{(-\alpha A + \beta B)\cos \pi\beta + (\beta A + \alpha B)\sin \pi\beta\} + (\alpha A - \beta B)\right] + PF\right\} = E$$

or

$$I = \frac{E}{ZW} \qquad (24)$$

in which

$$W = \frac{2}{K(\alpha^2 + \beta^2)}\left[\epsilon^{-\pi\alpha}\{(-\alpha A + \beta B)\cos \pi\beta + (\beta A + \alpha B)\sin \pi\beta\} - (-\alpha A + \beta B)\right] + PF \qquad (25)$$

Upon substituting the value of I from equation 24 into equation 23, there results that:

$$\frac{e}{E} = \frac{1}{W}\left\{\frac{2\pi}{K}\,\epsilon^{-2\pi\alpha\frac{t}{T}}\left[A \cos 2\pi\beta\frac{t}{T} - B \sin 2\pi\beta\frac{t}{T}\right] + PF\right\} \qquad (26)$$

The load current can be obtained by substituting equation 16 in equation 13 giving:

$$i_2 = I\left\{1 - \text{real part } \frac{\omega}{f}(-\alpha + j\beta)(A + jB)\epsilon^{\omega(-\alpha + j\beta)t}\right\}$$

or

$$\frac{i_2 Z}{E} = \frac{1}{W}\left\{1 + 2\pi\epsilon^{-2\pi\alpha\frac{t}{T}}\left[(\alpha A + \beta B)\cos 2\pi\beta\frac{t}{T} + (\beta A - \alpha B)\sin 2\pi\beta\frac{t}{T}\right]\right\} \qquad (27)$$

A summary of the necessary steps for calculation purposes would be worth while at this point. Given PF and K, it is required to determine R/X and $4YR$ from the relations

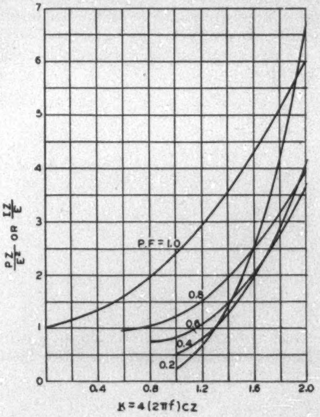


Fig. 7. Curves for evaluating power and magnitude of constant current in d-c side

$$\frac{R}{X} = \frac{PF}{\sqrt{1 - (PF)^2}} \qquad (28)$$

and

$$4YR = K\,(PF) \qquad (29)$$

The procedure is to determine α and β from equations 10 and 11; m and n from equation 17; and A and B from equations 20 and 21. Finally, W may be calculated from equation 25, and all the quantities necessary for substitution in equations 26 and 27 will have been obtained.

Roots Real

Consideration will be given next to the case in which the roots of equation 8 are real. The division between the 2 cases occurs for those values of R/X and $4YR$ that make β of equation 11 zero. This occurs when:

$$\frac{1}{4}\left(\frac{R}{X}\right)(4YR) = 1 \tag{30}$$

or expressed in terms of K and PF,

$$K = \frac{4\sqrt{1-(PF)^2}}{PF} \tag{31}$$

The curve relating K and PF for this limiting condition is shown in figure 3. It may be observed that because of the rapid rise in K for values of PF just less than unity and the fact that K is unlikely to have values larger than 1 or 2, there will be only a very small range of values of PF for which the roots are real. The principal exception is unity PF, a case that is considered in a previous paper.[1]

Because of the relative unimportance of the case involving real roots, the results only and not the development are given. Let

$$g = \frac{\pi}{2}\left(\frac{R}{X}\right) + \pi\sqrt{\frac{1}{K}\left(\frac{R}{X}\right)}\ \sqrt{\frac{K}{4}\left(\frac{R}{X}\right) - 1} \tag{32}$$

$$h = \frac{\pi}{2}\left(\frac{R}{X}\right) - \pi\sqrt{\frac{1}{K}\left(\frac{R}{X}\right)}\ \sqrt{\frac{K}{4}\left(\frac{R}{X}\right) - 1} \tag{33}$$

Thus

$$\frac{e}{E} = \frac{f_1}{f_2} \tag{34}$$

$$\frac{i_2 Z}{E} = \frac{1}{PF}\,\frac{f_3}{f_2} \tag{35}$$

$$I = \frac{E}{R}\,\frac{1}{f_2} \tag{36}$$

in which

$$f_1 = \frac{2(\pi - Kh)}{K(h-g)(1+\epsilon^{-g})}\,\epsilon^{\frac{-2g}{T}t} - \frac{2(\pi - Kg)}{K(h-g)(1+\epsilon^{-h})}\,\epsilon^{\frac{-2h}{T}t} + 1 \tag{37}$$

$$f_2 = \frac{2(\pi - Kh)(1-\epsilon^{-g})}{Kg(h-g)(1+\epsilon^{-g})} - \frac{2(\pi - Kg)(1-\epsilon^{-h})}{Kh(h-g)(1+\epsilon^{-h})} + 1 \tag{38}$$

$$f_3 = \frac{2}{\pi(h-g)}\,\frac{g(\pi - Kh)}{(1+\epsilon^{-g})}\,\epsilon^{\frac{-2g}{T}t} - \frac{2}{\pi(h-g)}\,\frac{h(\pi - Kg)}{(1+\epsilon^{-h})}\,\epsilon^{\frac{-2h}{T}t} + 1 \tag{39}$$

Graphical Presentation of Results

Examination of the expressions for e/E and i_2Z/E discloses that both are functions of PF and K alone. These quantities are plotted in figure 4 in the form of families of curves, each family being plotted for a constant value of PF and different values of K. These curves show the effect of varying the load inductance and the commutating capacitance upon the wave shapes, deionization time, current through the tube just before commutation, and the value of the negative voltage "kick" just after current zero. The curves may be used for any frequency, since the effect of frequency is incorporated in the values of X, Y, and T. While the abscissa scale for general purposes is provided by the t/T scale, a special scale is provided for the 60 cycle frequency.

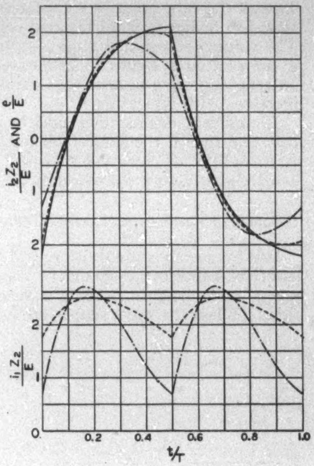


Fig. 8. Effect of different values of X_1 on i_2, i_1, and e for $PF = 1.0$ and $K = 1.0$

— $X_1/Z_2 = \infty$
----- $X_1/Z_2 = 0.6$
--- $X_1/Z_2 = 0.2$

The voltage e is the voltage across each of the 3 transformer windings on an equal turns basis. The capacitor voltage is twice this value. To obtain the drop across each tube, it should be remembered that during the conducting period the drop is, of course, the arc drop, but that during the nonconducting period it is (neglecting the arc drop) equal to the capacitor voltage. Thus, the anode-cathode voltage has an essentially constant value of about 5 to 20 volts during the conducting period. At the instant the current in the tube drops to zero, the voltage across the tube decreases suddenly to a negative value equal to $2E$ times the value of e/E given by the curves for $t = 0$. The voltage then increases, crosses zero, and when t/T equals 0.5 again drops to arc voltage.

To approximate the effect of arc drop, E in this development should represent the actual source voltage minus the arc drop. This will give correct values for i_2 and e. To get the anode-cathode voltage, it is necessary to multiply $2e/E$ by the actual source voltage minus the arc drop and then to add the arc drop to the product.

Deionization Time

The deionization time of the tube is dependent upon the magnitude and the rate of decay of anode current, anode-cathode voltage, grid voltage, and other factors. The circuit must be adjusted to suit the tube characteristics. As a measure of the circuit characteristics, the "deionization time" will be defined as the time from current zero to the time when the anode-cathode voltage first becomes positive. For satisfactory operation the actual deionization time of the tube must be considerably less than this time to prevent forward fire and consequent failure. The values defined in this manner, taken from figure 4, are plotted in figure 5 as functions of K and PF. In general, it may be seen that the deionization time increases with increasing K.

If sufficient deionization time be obtained at full load and then if the load be decreased by increasing Z, K and the deionization time will increase, which assures satisfactory operation at fractional loads.

Necessity for Commutating Capacitors

It is frequently stated with regard to inverters that sufficient capacitance should be used to correct the power factor and to provide sufficient deionization time. When the wave shapes are not sinusoidal the meaning of the foregoing is somewhat vague. In figure 6, the upper curve is plotted for $K = \sqrt{1-(PF)^2}$. This relation expresses the amount of capacitive kilovolt-amperes required to just correct the power factor if the voltage and current wave shapes be sinusoidal. The other 2 curves of figure 6 are plotted from data obtained from figure 5 and show the capacitive kilovolt-amperes required for a deionization time of zero and 0.1 T. It may be seen that the relation $K = \sqrt{1 - (PF)^2}$ gives a convenient rule-of-thumb method for evaluating the capacitance required; in all cases except for PF greater than 0.99, a deionization time in excess of 0.1 T is obtained with this relation.

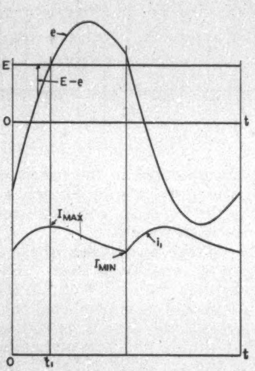


Fig. 9. Relation between e and i_1

Power Relations

Relations between power P, E, Z, and I readily are obtained from the expressions already developed.

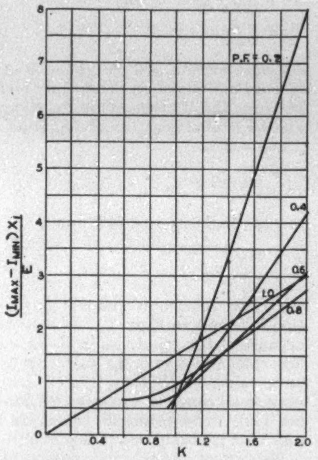


Fig. 10. Curves for estimating magnitude of variation of direct current

For the oscillatory case, from equation 24

$$\frac{IZ}{E} = \frac{1}{W} \tag{40}$$

and as $I = P/E$, then

$$\frac{PZ}{E^2} = \frac{1}{W} \tag{41}$$

For the nonoscillatory case, from equation 36

$$I = \frac{E}{(PF)Z}\,\frac{1}{f_2}$$

or

$$\frac{IZ}{E} = \frac{1}{(PF)\,f_2} \tag{42}$$

and as $I = P/E$, then

$$\frac{PZ}{E^2} = \frac{1}{(PF)\,f_2} \tag{43}$$

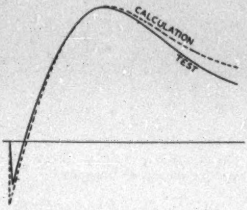
The quantities PZ/E^2 and IZ/E are plotted in figure 7 as functions of PF and K.

Applicability of Solution to Circuits of Finite Values of Ballast Inductance

To this point it has been assumed that the ballast inductance in the d-c side is infinitely large so that i_1 is constant. The question naturally arises as to how small the ballast inductance may be before the results are much different from that for infinite inductance. One can form some idea by referring to figures 1 and 8, which show the effect upon i_1, i_2, and e of varying the ratio X_1/Z for values of PF of 0.6 and 1.0, respectively. It may be observed that the magnitude of e/E and i_2Z/E are not affected very greatly, but the deionization time and the pulsations and magnitude of i_1Z/E are. It is necessary, therefore, to be careful in applying the results of figure 4 to i_1Z/E or the deionization time, except for large values of X_1/Z_2. The following method will give approximately the variations in i_1, the accuracy depending upon the value of X_1/Z_2.

Fig. 11. Comparison of test and calculated values of anode-cathode voltage

Calculated values are corrected for arc drop and ohmic drop in ballast reactor



In figure 9, the curve e shows the voltage across one winding of the transformer. The drop across the ballast inductance must be equal to the applied voltage E minus this voltage. When $(E - e)$ is positive, i_1 increases, and when $(E - e)$ is negative, i_1 decreases; $(E - e)$ is equal to the inductance L_1 times the time differential of i_1.

Therefore

$$E - e = \frac{X_1}{\omega}\frac{di_1}{dt} \tag{44}$$

The current i_1 decreases from its maximum value, I_{max}, at some time t_1, when $(E - e)$ is equal to zero, to a minimum at t equal to $T/2$ or at some previous time if $(E - e)$ becomes zero again before the end of the half cycle. Introducing such limits in the integral of equation 44,

$$\int_{I_{max}}^{I_{min}} di_1 = \frac{\omega}{X_1}\int_{t_1}^{\frac{T}{2}\text{ or }t_2} (E - e)\, dt$$

and changing the independent variable,

$$\frac{(I_{max} - I_{min})X_1}{E} = -2\pi \int_{\frac{t_1}{T}}^{\frac{1}{2}\text{ or }\frac{t_2}{T}} \left(1 - \frac{e}{E}\right) d\left(\frac{t}{T}\right)$$

This integration can be accomplished most readily by mechanical means and has been carried out for the curves of figure 4. The results are plotted in figure 10. Note particularly that the reactance X_1 is based upon control frequency and *not* upon double control frequency.

The accuracy of this relation depends not only upon X_1 but also upon the values of K and PF. In table I are tabulated data obtained from a previous paper[1] by the author showing $\frac{(I_{max} - I_{min})X_1}{E}$ for different values of X_1/Z and different values of K for unity PF. These values may be compared with the values tabulated in the bottom row obtained from figure 10 which correspond to the case for which X_1/Z is infinite. It may be observed that the approximation becomes more accurate the greater X_1/Z becomes. Similar data for PF equal to 0.6 obtained from figure 1 give values of $\frac{(I_{max} - I_{min})X_1}{E}$ of 0.82 and 1.08 for X_1/Z equal to 1.0 and 5.0, respectively, as contrasted with 1.15 for X_1/Z equal to infinity, the value obtained from figure 10.

COMPARISON OF TEST AND CALCULATED RESULTS

Figure 11 shows a comparison of test and calculated values of anode-cathode voltage for a circuit in which $PF = 0.849$, $K = 0.679$, and $X_1/Z_2 = 0.65$.

Table I—Values of $\frac{(I_{max} - I_{min})X_1}{E}$ for PF = 1.0

$\frac{X_1}{Z}$	K = 0.2	K = 0.4	K = 0.7	K = 1.0
0.2	0.25	0.46		
0.6	0.28	0.54	0.83	1.23
1.0	0.31	0.51	0.93	1.35
2.0	0.32	0.60	1.02	1.52
∞	0.30	0.60	1.05	1.50

For the purposes of calculation it was assumed that X_1/Z_2 equaled infinity. Corrections were made for arc drop and IR drop in the ballast inductance.

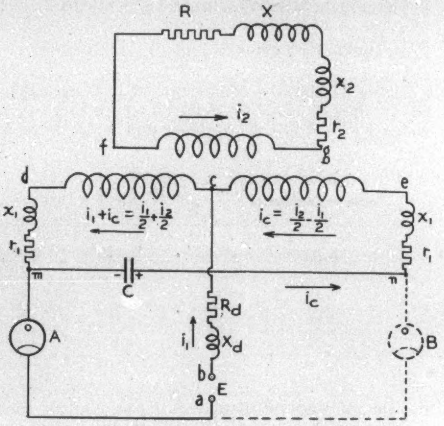
Appendix

In the development that follows the effect of finite values of ballast inductance in the d-c circuit is taken into consideration. The only important simplifying assumption is that the magnetizing current of the transformer is neglected. The circuit under consideration for the period during which tube A is conducting is shown by the full lines of figure 12. The following symbols are used:

E = applied voltage
f = control frequency
$\omega = 2\pi f$
$T = 1/f$ = period of control frequency
L_d = ballast inductance in henries
$X_d = \omega L_d$ = reactance in ohms of ballast inductance at control frequency (*not* at double control frequency)
R_d = resistance of ballast inductance
L = inductance of load in henries
$X = \omega L$ = reactance of load in henries
R = resistance of load in ohms
C = capacitance of commutating capacitor in farads
$Y = \omega C$ = admittance of commutating capacitor in mhos
l_1 = equivalent inductance of one primary winding of transformer in henries
x_1 = equivalent reactance at control frequency of one primary winding of transformer in ohms
l_2 = equivalent inductance of secondary winding of transformer in henries

x_2 = equivalent reactance at control frequency of secondary winding of transformer
r_1 = resistance of one primary winding of transformer in ohms
r_2 = resistance of secondary winding of transformer in ohms
i_1 = current in d-c side in amperes
i_2 = load current in amperes
i_c = capacitor current in amperes
e_c = voltage across the equivalent capacitor $4C$ in volts
q_1 = charge on capacitor C in coulombs

It is assumed that the transformer has 3 windings each of the same number of turns and that the actual impedances in the load are reduced to those corresponding to the number of turns in each of the primary windings. The plan is to set up the differential equations for the circuit involved when one tube is conducting and determine the integration constants from the following terminal conditions:



R
X
x_2
i_2
r_2
f
g
d
c
e
x_1
r_1
$i_1 + i_c = \frac{i_1}{2} + \frac{i_2}{2}$
$i_c = \frac{i_2}{2} - \frac{i_1}{2}$
x_1
r_1
m
− +
C
n
R_d
i_c
i_1
X_d
A
B
b
E
a

Fig. 12. Schematic diagram of inverter circuit

$$i_1\ (\text{for } t = 0) = i_1\left(\text{for } t = \frac{T}{2}\right) \tag{45}$$

$$i_2\ (\text{for } t = 0) = -\,i_2\left(\text{for } t = \frac{T}{2}\right) \tag{46}$$

$$e_c\ (\text{for } t = 0) = -\,e_c\left(\text{for } t = \frac{T}{2}\right) \tag{47}$$

For the assumption of zero magnetizing current in the transformer, the algebraic sum of the magnetizing effect of the currents in the 3 windings upon the core must be equal to zero. Thus, by the aid of figure 12,

$$(i_1 + i_c) + i_c - i_2 = 0 \tag{48}$$

or

$$i_c = \frac{i_2}{2} - \frac{i_1}{2} \tag{49}$$

and

$$i_1 + i_c = \frac{i_1}{2} + \frac{i_2}{2} \tag{50}$$

The last 2 expressions determine the currents in the 2 primary windings. It has been shown by Peters and Skinner[2,3] that the characteristics of a 3 winding transformer in which the magnetizing current is negligibly small can be represented by 3 equivalent impedances, one in series with each of the 3 windings. These in the present notation have been designated x_1, x_2, r_1, and r_2.

The differential equations may now be written, keeping in mind that the potentials of *c* above *d*, of *e* above *c*, and of *g* above *f* are all equal. For the circuit consisting of *bcgfdmab*,

$$\begin{aligned} E &= R_d i_1 + \frac{X_d}{\omega}\frac{di_1}{dt} + (r_2 + R)i_2 + \frac{(x_2 + X)}{\omega}\frac{di_2}{dt} + \\ &\qquad r_1\left(\frac{i_1}{2} + \frac{i_2}{2}\right) + \frac{x_1}{\omega}\frac{d}{dt}\left(\frac{i_1}{2} + \frac{i_2}{2}\right) \\ &= \left(R_d + \frac{r_1}{2}\right)i_1 + \frac{\left(X_d + \frac{x_1}{2}\right)}{\omega}\frac{di_1}{dt} + \left(R + r_2 + \frac{r_1}{2}\right)i_2 + \\ &\qquad \frac{\left(X + x_2 + \frac{x_1}{2}\right)}{\omega}\frac{di_2}{dt} \end{aligned} \tag{51}$$

and for the circuit *mnegfdm*,

$$\begin{aligned} -\frac{\omega q_1}{Y} + r_1\left(\frac{i_2}{2} - \frac{i_1}{2}\right) + \frac{x_1}{\omega}\frac{d}{dt}\left(\frac{i_2}{2} - \frac{i_1}{2}\right) + 2\Bigg[(R + r_2)i_2 + \\ \frac{(X + x_2)}{\omega}\frac{di_2}{dt}\Bigg] + r_1\left(\frac{i_1}{2} + \frac{i_2}{2}\right) + \frac{x_1}{\omega}\frac{d}{dt}\left(\frac{i_1}{2} - \frac{i_2}{2}\right) = 0 \end{aligned}$$

or

$$-\frac{\omega q_1}{2Y} + \left(R + r_2 + \frac{r_1}{2}\right)i_2 + \frac{1}{\omega}\left(X + x_2 + \frac{x_1}{2}\right)\frac{di_2}{dt} = 0 \tag{52}$$

Now to simplify the notation, let

$$R_1 = R_d + \frac{r_1}{2} \tag{53}$$

$$R_2 = R + r_2 + \frac{r_1}{2} \tag{54}$$

$$X_1 = X_d + \frac{x_1}{2} \tag{55}$$

$$X_2 = X + x_2 + \frac{x_1}{2} \tag{56}$$

Thus equations 52 and 53 become, respectively,

$$E = R_1 i_1 + \frac{X_1}{\omega}\frac{di_1}{dt} + R_2 i_2 + \frac{X_2}{\omega}\frac{di_2}{dt} \tag{57}$$

$$-\frac{\omega q_1}{2Y} + R_2 i_2 + \frac{X_2}{\omega}\frac{di_2}{dt} = 0 \tag{58}$$

Also from figure 12 it may be seen that

$$i_1 - i_2 = 2\frac{dq_1}{dt} \tag{59}$$

Previously it has been stated that the characteristics of the transformer can be represented by assuming a perfect transformer with certain series impedances. A further circuit simplification can be made by eliminating the transformer entirely as shown in figure 13. The 3 differential equations corresponding to this network are

$$E = R_1 i_1 + \frac{X_1}{\omega}\frac{di_1}{dt} + R_2 i_2 + \frac{X_2}{\omega}\frac{di_2}{dt} \tag{60}$$

$$-\frac{\omega q}{4Y} + R_2 i_2 + \frac{X_2}{\omega}\frac{di_2}{dt} = 0 \tag{61}$$

$$\frac{dq}{dt} = i_1 - i_2 \tag{62}$$

It may be seen that, if q equals $2q_1$, this circuit is equivalent to that of figure 12. Because of its similarity to the circuit used in the body of the paper and its greater simplicity, this equivalent network and its corresponding equations will be used in this development. Now let

$$i_1 = A_1\epsilon^{mt} \qquad (63)$$

$$i_2 = A_2\epsilon^{mt} \qquad (64)$$

$$q = A_3\epsilon^{mt} \qquad (65)$$

and substitute in equations 60 to 62. After rearranging the terms,

$$\left(R_1 + m\frac{X_1}{\omega}\right)A_1 + \left(R_2 + m\frac{X_2}{\omega}\right)A_2 = 0 \qquad (66)$$

$$\left(R_2 + m\frac{X_2}{\omega}\right)A_2 - \frac{\omega A_3}{4Y} = 0 \qquad (67)$$

$$A_1 - A_2 - mA_3 = 0 \qquad (68)$$

The solution of the equation formed by setting the determinant of these 3 equations equal to zero provides values of m which satisfy the 3 equations. Thus

$$m^3 + \omega\left(\frac{R_2}{X_2} + \frac{R_1}{X_1}\right)m^2 + \omega^2\left[\frac{R_1R_2}{X_1X_2} + \frac{1}{4Y}\left(\frac{1}{X_1} + \frac{1}{X_2}\right)\right]m + \frac{\omega^3(R_1 + R_2)}{4YX_1X_2} = 0$$

Let the roots of this cubic be $\omega m'$, $\omega m''$, and $\omega m'''$. The coefficients m', m'', and m''' can also be obtained by solving the following cubic:

$$m^3 + \left(\frac{R_2}{X_2} + \frac{R_1}{X_1}\right)m^2 + \left[\frac{R_1R_2}{X_1X_2} + \frac{1}{4Y}\left(\frac{1}{X_1} + \frac{1}{X_2}\right)\right]m + \frac{R_1 + R_2}{4YX_1X_2} = 0 \qquad (69)$$

The complementary functions can then be written

$$i_1 = A_1'\epsilon^{\omega m't} + A_1''\epsilon^{\omega m''t} + A_1'''\epsilon^{\omega m'''t} \qquad (70)$$

$$i_2 = A_2'\epsilon^{\omega m't} + A_2''\epsilon^{\omega m''t} + A_2'''\epsilon^{\omega m'''t} \qquad (71)$$

$$q = A_3'\epsilon^{\omega m't} + A_3''\epsilon^{\omega m''t} + A_3'''\epsilon^{\omega m'''t} \qquad (72)$$

The integration constants are related through equations 66 and 67. Thus,

$$A_2' = -\frac{R_1 + m'X_1}{R_2 + m'X_2}A_1' \qquad (73)$$

$$A_3' = -\frac{4Y(R_1 + m'X_1)}{\omega}A_1' \qquad (74)$$

Instead of carrying the quantity q through the development, it will be more convenient to use the quantity e_c, which is equal to $\omega q/4Y$. Thus the coefficient of the first term in e_c is

$$A_4' = \frac{\omega A_3'}{4Y} = -(R_1 + m'X_1)A_1' \qquad (75)$$

and similarly for the other terms. The complementary function for this quantity is thus

$$e_c = A_4'\epsilon^{\omega m't} + A_4''\epsilon^{\omega m''t} + A_4'''\epsilon^{\omega m'''t} \qquad (76)$$

The particular integrals for the 3 quantities i_1, i_2, and e_c are

$$i_1 = \frac{E}{R_1 + R_2} \qquad (77)$$

$$i_2 = \frac{E}{R_1 + R_2} \qquad (78)$$

$$e_c = \frac{R_2}{R_1 + R_2}E \qquad (79)$$

If the coefficients of the transient terms be made dimensionless, the results will have wider applicability. This can be accomplished by expressing the results in the form of expressions

$\frac{i_1(R_1 + R_2)}{E}$, $\frac{i_2(R_1 + R_2)}{E}$, and $\frac{e_c}{E}$. Thus if

$$B_1' = A_1'\frac{(R_1 + R_2)}{E} \qquad (80)$$

and similarly for B_1'' and B_1''', then by combining the complementary functions expressed by equations 60, 61, and 76 with the particular integrals expressed by equations 77 to 79,

$$\frac{i_1(R_1 + R_2)}{E} = B_1'\epsilon^{2\pi m'\frac{t}{T}} + B_1''\epsilon^{2\pi m''\frac{t}{T}} + B_1'''\epsilon^{2\pi m'''\frac{t}{T}} + 1 \qquad (81)$$

$$\frac{i_2(R_1 + R_2)}{E} = -\frac{R_1 + m'X_1}{R_2 + m'X_2}B_1'\epsilon^{2\pi m'\frac{t}{T}} - \frac{R_1 + m''X_1}{R_2 + m''X_2}B_1''\epsilon^{2\pi m''\frac{t}{T}} - \frac{R_1 + m'''X_1}{R_2 + m'''X_2}B_1'''\epsilon^{2\pi m'''\frac{t}{T}} + 1 \qquad (82)$$

$$\frac{e_c}{E} = -\frac{(R_1 + m'X_1)}{R_1 + R_2}B_1'\epsilon^{2\pi m'\frac{t}{T}} - \frac{(R_1 + m''X_1)}{R_1 + R_2}B_1''\epsilon^{2\pi m''\frac{t}{T}} - \frac{(R_1 + m''X_1)}{R_1 + R_2}B_1'''\epsilon^{2\pi m'''\frac{t}{T}} + \frac{R_2}{R_1 + R_2} \qquad (83)$$

In these expressions, the exponents were changed from the form $\omega m't$ to the form $2\pi m't/T$.

The 3 integration constants can be determined by applying the 3 terminal conditions expressed by equations 45, 46, and 47. Thus

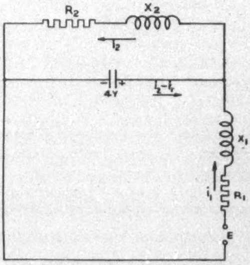
$$(1 - \epsilon^{\pi m'})B_1' + (1 - \epsilon^{\pi m''})B_1'' + (1 - \epsilon^{\pi m'''})B_1''' = 0 \qquad (84)$$

$$(1 + \epsilon^{\pi m'})\frac{R_1 + m'X_1}{R_2 + m'X_2}B_1' + (1 + \epsilon^{\pi m''})\frac{R_1 + m''X_1}{R_2 + m''X_2}B_1'' + (1 + \epsilon^{\pi m'''})\frac{R_1 + m'''X_1}{R_2 + m'''X_2}B_1''' = 2 \qquad (85)$$

$$(1 + \epsilon^{\pi m'})\frac{(R_1 + m'X_1)}{R_2}B_1' + (1 + \epsilon^{\pi m''})\frac{(R_1 + m'X_1)}{R_2}B_1'' + (1 + \epsilon^{\pi m'''})\frac{(R_1 + m'''X_1)}{R_2} = 2 \qquad (86)$$

After evaluating the integration constants from equations 84 to 86, the solutions are obtained by inserting the constants in equations 81 to 83. Where complex roots of equation 69 occur, they occur in pairs which are conjugate. If m'' and m''' be the conjugate roots, B_1'' and B_1''' also must be conjugate. It is simpler, therefore, to replace these coefficients by $a + jb$ and $a - jb$, respectively, and solve for the 2 real coefficients.

Fig. 13. Equivalent circuit of single phase inverter



NUMERICAL EXAMPLE

To illustrate the calculations the following constants are assumed:

$$\frac{X_2}{R_2} = 1.333 \qquad \frac{X_1}{R_2} = 8.333 \qquad \frac{R_1}{R_2} = 0 \qquad 4YR_2 = 0.72$$

These constants correspond to

$$PF = \frac{R_2}{\sqrt{R_2^2 + X_2^2}} = 0.6$$

$$K = 1.2$$

$$\frac{X_1}{Z_2} = \frac{X_1}{\sqrt{R_2^2 + X_2^2}} = 5$$

Inasmuch as the expressions are dimensionless, it is simpler to assume R_2 as unity and use for the other constants the values computed by the given ratios. Thus,

$$R_2 = 1.0 \qquad X_2 = 1.333 \qquad 4Y = 0.72$$
$$R_1 = 0 \qquad X_1 = 8.333$$

On substituting these values in equation 69,

$$m^3 + 0.75\, m^2 + 1.208\, m + 0.125 = 0$$

The roots of this cubic are

$$m' = -0.110$$
$$m'' = -0.320 + j\,1.018$$
$$m''' = -0.320 - j\,1.018$$

In preparation for solving equations 84 to 86 the following are calculated:

$$\epsilon^{\pi m'} = 0.780$$

$$\epsilon^{\pi m''} = -0.365 - j\,0.0202$$

$$\epsilon^{\pi m'''} = -0.365 + j\,0.0202$$

$$\frac{(1 + \epsilon^{\pi m'})(R_1 + m'X_1)}{R_2} = (1.708)(-0.110)(8.33) = -1.564$$

$$\frac{(1 + \epsilon^{\pi m''})(R_1 + m''X_1)}{R_2} = (0.635 - j\,0.0202)[0 + (-0.320 + j\,1.018)]\,8.333 = -1.522 + j\,5.4$$

$$\frac{(1 + \epsilon^{\pi m'''})(R_1 + m'''X_1)}{R_2} = -1.522 - j\,5.44$$

$$\frac{(1 + \epsilon^{\pi m'})(R_1 + m'X_1)}{R_2 + m'X_2} = \frac{-1.564}{1 + (-0.110)(1.333)} = -1.832$$

$$\frac{(1 + \epsilon^{\pi m''})(R_1 + m''X_1)}{R_2 + m''X_2} = \frac{-1.522 + j\,5.44}{1 + (-0.320 + j\,1.018)(1.333)} = 3.00 + j\,2.39$$

$$\frac{(1 + \epsilon^{\pi m'''})(R_1 + m'''X_1)}{R_2 + m'''X_2} = 3.00 - j\,2.39$$

After substituting the numerical values in equations 84 to 86 there results

$$0.292\, B_1' + (1.366 + j\,0.0202)\, B_1'' + (1.366 - j\,0.0202)\, B_1''' = 0$$
$$-1.83\, B_1' + (3.00 + j\,2.39)\, B_1'' + (3.00 - j\,2.39)\, B_1''' = 2$$
$$-1.56\, B_1' + (-1.522 + j\,5.44)\, B_1'' + (-1.522 - j\,5.44)\, B_1''' = 2$$

Since B_1'' and B_1''' are conjugate, let

$$B_1'' = a + jb \qquad B_1''' = a - jb$$

Then

$$0.292\, B_1' + 2.73\, a - 0.0404\, b = 0$$
$$-1.83\, B_1' + 6.00\, a - 4.78\, b = 2$$
$$-1.56\, B_1' - 3.04\, a - 10.87\, b = 2$$

The solutions of these equations are

$$B_1' = -0.589$$
$$a = 0.0611$$
$$b = -0.1165$$

In the preparation for evaluating the final expressions, the following coefficients for equations 82 and 83 are computed:

$$-\frac{R_1 + m'X_1}{R_1 + R_2} B_1' = -(-0.110)(8.333)(-0.589) = -0.539$$

$$-\frac{(R_1 + m''X_1)B_1''}{R_1 + R_2} = -(-0.320 + j\,1.018)(8.333)(0.0611 - j\,0.1165) = -0.825 - j\,0.829$$

$$-\frac{(R_1 + m'X_1)B_1'}{R_2 + m'X_2} = \frac{-0.539}{1 + (-0.110)(1.333)} = -0.632$$

$$-\frac{(R_1 + m''X_1)B_1''}{R_2 + m''X_2} = \frac{-0.825 - j\,0.829}{1 + (-0.320 + j\,1.018)(1.333)} = -0.736 + j\,0.297$$

On substituting the numerical values in equations 81 to 83

$$\frac{i_1(R_1 + R_2)}{E} = -0.589\, \epsilon^{-0.690\frac{t}{T}} + 2[\text{real part } (0.0611 - j\,0.1165)\, \epsilon^{-2.01\frac{t}{T} + j\,6.40\frac{t}{T}} + 1.0$$

$$= -0.589\, \epsilon^{-0.690\frac{t}{T}} + \epsilon^{-2.01\frac{t}{T}}\left(0.122 \cos 6.40 \frac{t}{T} + 0.230 \sin 6.40 \frac{t}{T}\right) + 1.0$$

$$\frac{i_2(R_1 + R_2)}{E} = -0.632\epsilon^{-0.690\frac{t}{T}} + 2\left[\text{real part } (-0.736 + j\,0.297)\, \epsilon^{-2.01\frac{t}{T} + j\,6.40\frac{t}{T}}\right] + 1.0$$

$$= -0.632\epsilon^{-0.690\frac{t}{T}} + \epsilon^{-2.01\frac{t}{T}}\left(-1.472 \cos 6.40 \frac{t}{T} - 0.593 \sin 6.40 \frac{t}{T}\right) + 1.0$$

$$\frac{e_c}{E} = -0.539\epsilon^{-0.690\frac{t}{T}} + 2\left[\text{real part } (-0.825 - j\,0.829)\epsilon^{-2.01_T + j\,6.40\frac{t}{T}}\right] + 1.0$$

$$= -0.539\epsilon^{-0.690\frac{t}{T}} + \epsilon^{-2.01\frac{t}{T}}\left(-1.65 \cos 6.40 \frac{t}{T} + 1.658 \sin 6.40 \frac{t}{T}\right) + 1.0$$

The foregoing quantities are plotted in figure 1.

References

1. Parallel Inverter With Resistance Load, C. F. Wagner. Elec. Engg. (A.I.E.E. Trans.), v. 54, Nov. 1935, p. 1227–35.

2. Transformers for Interconnecting High Voltage System, J. F. Peters and M. E. Skinner. A.I.E.E. Trans., v. 40, 1921, p. 1181.

3. Symmetrical Components (a book), C. F. Wagner and R. D. Evans. McGraw-Hill Book Co., New York, N. Y., 1933, p. 114.

4. The Parallel Type Inverter, F. N. Tompkins. A.I.E.E. Trans., v. 51, Sept. 1932, p. 707–14.

5. Die Berechnung der Elektrischen Verhältnisse in Einphasigen Selbsterregten Wechselrichter, Walter Schilling. *Archiv. für Elektrotechnik*, v. 28, 1933, p. 22–34.

6. Die Berechnung des Parallelwechselrichters bei Ohmischer Belastung, Walter Schilling. *Archiv. für Elektrotechnik*, v. 29, 1935, p. 119–30.

7. Untersuchung der Frequenzhaltung am Selbstgesteurten und Selbstgeführten Parallelwechselrichter im Resonanzahnlichen Zustand, H. U. Neidhardt. *Archiv. für Elektrotechnik*, v. 29, 1935, p. 241–58.

8. Stromlöschung, Wellenform und Blindlastung bei Wechselrichtern, Alfred von Engel and Hans Klemperer. *Wissenschaftliche Veröffentlichungen aus dem Siemens-Konzern*, v. 13, part 2, p. 38–62.

Heater-Cathode Insulation Performance

The insulation between the heater wire and the cathode of electronic tubes of the indirectly heated cathode type is required to conduct heat while maintaining high electrical resistance at operating temperatures. By means of cathode-ray oscillograms the effects of operating temperature, heat treatment, and impurities upon the electrical conduction of the commonly used insulating materials are shown in this paper.

By
HANS KLEMPERER
MEMBER A.I.E.E.
Westinghouse Elec. and Mfg. Co., East Pittsburgh, Pa.

A PROBLEM in designing indirectly heated cathodes for electronic tubes is to provide a thermal connection between heater wire and cathode sleeve, operating in a vacuum at temperatures between 800 and 1,200 degrees centigrade, and at the same time to secure electrical insulation between heater and cathode circuits.

The high degree of mechanical stability required for the heater-cathode system combined with the smallness of space inside the cathode sleeve prohibits the use of a high vacuum for insulation. Furthermore, electron emission from the hot metal surfaces, although relatively small at the temperatures involved, would be increased greatly by diffusion of barium particles from the outside of the cathode. The necessity of maintaining a high vacuum within the tube prohibits the use of insulating materials that would develop an appreciable vapor pressure, or react chemically with the metals used for heater wire and cathode sleeve (tungsten and nickel).

INSULATOR MATERIALS

At the present time best results are obtained by using oxides of the lightest metals, such as lithium oxide (Li_2O), beryllium oxide (BeO), magnesium oxide (MgO), or aluminum oxide (Al_2O_3) as insulators. Standing in the upper series of the periodic system, these atoms have comparatively high ionization potentials. The oxygen atom is the foremost electronegative one and the light metals are strongly electropositive. Therefore, their chemical compounds form molecules which are not easily dissociated by electric stress or thermal movement. The molecular structure of these oxides is balanced electrically so well that at low temperatures practically no free electrons are moving between them to cause electric conductivity.

The excellent insulating properties of the oxides mentioned are available, however, only if the oxides are free from impurities. For instance, very small quantities of sulphur or phosphorus (see figure 6) as well as water and oxygen residuals can provide a large ionic conductivity. They change completely the electrical characteristic of the insulator, especially in the hot state. Therefore, the present objective is to develop simple and reliable processes to keep impurities within tolerable limits rather than to change the basic insulator material now in use.

At the time indirectly heated cathodes were introduced the cathode consisted of a metal tube in the center of which a straight tungsten heater wire was placed. The space between heater wire and cathode was filled completely by the insulator, a construction that resulted in a very large heat inertia—it took minutes to bring the cathode to operating temperature—and furthermore the insulation was poor (see figure 3). Great improvement came from the attempt to reduce the quantity of insulating material by placing it only where it actually was needed: around the heater wire. In modern tubes the heater element is wound in a double helical spiral or other form to neutralize its magnetic field. The tungsten wire forming it is sprayed with or dipped in a suspension in water of the insulating oxide, usually aluminum oxide, so that the surface of the wire is completely coated. The suspension of the oxide is ground carefully for 24 hours in a ball mill, and an organic binder is added to make it adhere to the heater wire. The binder evaporates during the firing process. The coated heater wire is dried in air and fired for about 5 minutes in a vacuum or dried hydrogen at about 1,700 degrees centigrade. After such heat treatment the insulation forms a rather solid and uniform layer about 0.5 millimeter thick around the heater wire. The heater so coated is inserted into a nickel sleeve, touching it at many points under light pressure. The nickel sleeve carries the emitting coating composed of about 75 per cent barium oxide (BaO) and 25 per cent strontium oxide (SrO) on its outer surface. Normally the cathode surface has an emitting temperature of 850 degrees centigrade and the temperature of the heater wire inside, as taken from resistance measurements, is about 1,000 degrees centigrade. In automobile radio receivers the tubes are operated at voltages between 5.5 and 8 volts. Corresponding surface and heater temperatures range from 800 to 950 degrees and from 950 to 1,200 degrees, respectively.

In most radio circuits the heater is a-c operated, and hum at the power supply frequency, caused by the reversing voltage drop along the heater wire (6.3 volts effective value in modern tubes) must not appear in the plate circuit. Some superheterodyne circuits apply the oscillator voltage in the cathode

---

A paper recommended for publication by the A.I.E.E. committee on communication, and tentatively scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., January 25–29, 1937. Manuscript submitted October 13, 1935; released for publication June 2, 1936.

The experiments upon which this paper is based were made by the author in 1934 in the laboratories of the RCA Radiotron Company, Harrison, N. J.

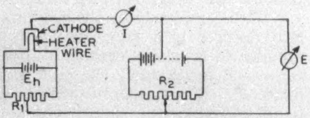
circuit, so that radio frequency voltage exists between heater and cathode. Especially in such circuits the heater-cathode impedance must be large to avoid trouble.

The cathode is the most expensive part in radio tube manufacturing and, therefore, receives serious consideration. Although insulating materials such as beryllium oxide (BeO) and processes such as vacuum firing result in the highest quality, they are not generally used because of the greater expense. However, they will be dealt with in this paper as they help the physical understanding.

Methods for Investigation of the Electric Properties of Heater-Cathode Insulation

This paper discusses tests for heater-cathode insulation, some of them made under exaggerated electric and thermal conditions, that give an insight into the physical behavior of the material rather than commercial tests for use under operating conditions.

Fig. 1. Circuit for d-c measurements of heater-cathode insulation



Such knowledge of physical behavior is gained by applying external potentials up to several hundred volts between heater and cathode and measuring the resulting current flow as illustrated in figure 1. The resistances R_1 and R_2 are small compared to the resistance of the heater-cathode insulation. The cathode is connected to ground. To avoid effects of thermionic cathode emission into the surrounding space all free electrodes of the tubes tested were connected to the cathodes.

The heater voltage E_h causes the observed voltage-current characteristic to differ from the actual voltage-current characteristic of the insulating material. The actual voltage across the insulator is $E + E_h/2$ at one end and $E - E_h/2$ at the other end of the heater wire. Therefore, if E is applied between the center tap of the heater battery and the cathode, the observed total current is

$$I = \frac{1}{E_h}\int_{E-\frac{E_h}{2}}^{E+\frac{E_h}{2}} i\,dE$$

Because of the geometrical configuration and material properties, the current i is not distributed linearly along the heater wire. Therefore any sharp break in the actual voltage-current characteristic of the material is somewhat displaced or smoothed in the observed characteristics. In the extreme case the observed characteristic may differ from the actual one by not more than E_h for any particular value of i.

Many of the voltage-current characteristics measured with continuous voltage show a definite time lag in reaching stable values, varying from fractions of a second to minutes. The longer times observed are similar to an "aging" effect and change the characteristic of the insulation in an irreproducible way. They are not considered at present, since such insulators are below the range of applicability in electronic tubes. The shorter time lags or hysteresis effects are, however, of special interest, and inasmuch as they cannot be examined properly by d-c measurements, a-c tests were made with a cathode-ray tube. The circuit is shown in figure 2.

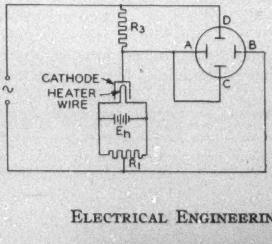
Plates A and B of the cathode ray tube measure the voltage drop across the heater-cathode insulation. Plates C and D measure the voltage caused by the current through the insulation which flows through resistor R_3, a one megohm resistor. A 60 cycle alternating voltage of 180 volts peak was applied. A straight line on the oscillograph screen, crossing the voltage and current axes at 45 degrees and going through the center point, indicated an insulation of pure ohmic resistance of one megohm, without hysteresis and without counter electromotive force. Hysteresis effects appeared as a loop, counter-potentials caused off-center crossings, and non-linearities bent the straight line into a curve.

The data obtained from the tests described are not quantitative. They cannot be interpreted in terms of specific resistance over the voltage range of the experiments since they are obtained on conventional tube structures. In these structures neither the temperature distribution across the insulator nor the distance from heater to cathode is accurately definable. Experiments with systems less complicated than indirectly heated cathodes are necessary for completeness.

Discussion of Experimental Results

The following test results show that perfection in heater-cathode insulation is not yet reached, but that it is possible to approach fair operating conditions. (A cathode is called "good" if at the highest operating temperature it has a resistance of about 10^7 ohms.) Figure 3 presents the voltage-current oscillogram of the old type cathode system, in which the whole space between heater wire and cathode was filled by the insulating material. The resistance of the insulating material (at rated temperature) remains constant at 2 megohms across the whole voltage range. In modern tubes, such as described hereinbefore, the insulation is in tight contact with the heater wire, but it touches the cathode only at

Fig. 2. Circuit for a-c measurements of heater-cathode insulation



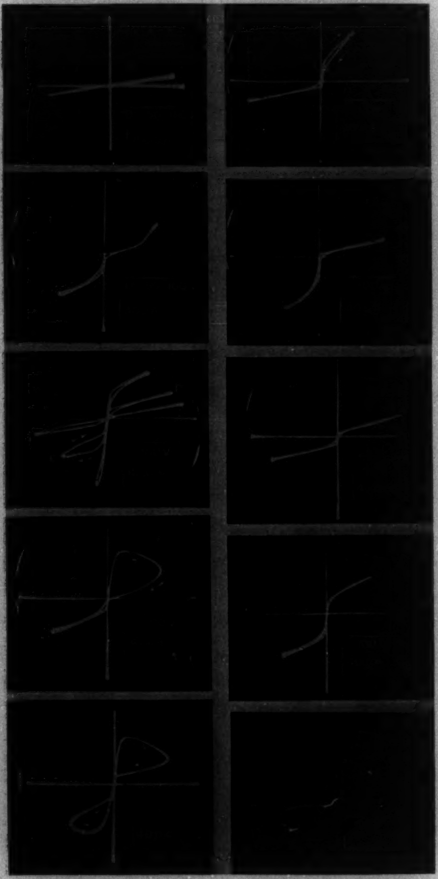
discrete points. These contact points are a source of nonlinearities in the voltage-current characteristic.

Figure 4 is the characteristic of such a modern heater-cathode system. Electron flow from cathode to heater wire (right side of all oscillograms) meets less resistance at higher voltage while in the opposite direction the resistance is low at low voltage and rises with increasing voltage. This oscillogram is typical of modern cathodes of fair quality. The nonlinearity on the left side is probably caused by limited conduction across the insulator while the high initial resistance on the right side is explained as high contact resistance, which breaks down at increasing field strength (at about 4,000 volts per centimeter). Slight loops in this oscillogram indicate that there is some small time delay between current and voltage, but the times observed are still small enough to suggest that current conduction is almost an electronic phenomenon.

A somewhat inferior cathode at 3 different temperatures gave the results presented in figure 5. At 700 degrees centigrade (curve *a*) the voltage-current line is almost linear, and only a small loop is visible on the left side; at 850 degrees centigrade (curve *b*) a larger loop is visible on the left side, and on both sides, especially on the right, it may be observed that the current does not follow the voltage rise substantially beyond a certain value. This phenomenon will be discussed later in more detail. At 950 degrees centigrade (curve *c*) the resistance is very low on the left side, but the current limiting or blocking phenomenon is still visible on the right side.

It appears that less severe heat treatment of the cathode presented in figure 5 is responsible for the increased ionic conductivity. This phenomenon was exaggerated in the 2 cathodes represented by the curves in figures 6 and 7. The cathode represented by the curve in figure 6 was fired at too low a temperature (1,600 degrees centigrade) and the hydrogen in which the firing took place was not dry. A large loop is visible on the right side of the oscillogram (heater wire positive). In this cathode insulator the amount of free oxygen was so large that the tungsten heater wire became oxidized after a few days of operation. The curve for the other cathode (figure 7) shows large loops on both sides. This cathode insulation consisted of carefully heat treated aluminum oxide (fired 5 minutes at 1,600 degrees in dried hydrogen), but it contained 0.5 per cent phosphorus pentoxide (P_2O_5) as a contamination. Similar tests with silicon dioxide (SiO_2) and tantalum pentoxide (Ta_2O_5) confirmed the fact that such contaminations are responsible for the observed electrolytic behavior.

Static measurements of such ionic or electrolytic insulations often show counterpotentials up to one volt. Such counterpotentials are able to produce currents of the order of 10^{-7} ampere for some seconds. If the cathode is cooled before the discharge takes



Figs. 3–12. Voltage-current oscillograms of heater-cathode insulation

Scales are in volts (*V*) and microamperes (*μA*)

Figure Number	Material of Insulation	Temperature of Cathode Surface, Degrees Centigrade	Heat Treatment, Temperatures in Degrees Centigrade
3	Magnesium oxide (MgO)	850	
4	Aluminum oxide (Al_2O_3)	850	Fired in vacuum at 1,650
5	Aluminum oxide (Al_2O_3)	700 (curve *a*)	
		850 (curve *b*)	
		950 (curve *c*)	Fired in vacuum at 1,600
6	Aluminum oxide (Al_2O_3)	900	Fired in wet hydrogen at 1,600
7	Aluminum oxide (Al_2O_3) and 0.5 per cent phosphorus pentoxide (P_2O_5)	950	Fired in dry hydrogen at 1,600
8	Aluminum oxide (Al_2O_3)	1,050	Fired in vacuum at 1,700
9	Aluminum oxide (Al_2O_3)	1,050	Fired in vacuum at 1,700
10	Aluminum oxide (Al_2O_3) and 1.0 per cent barium oxide (BaO)	1,050	Fired in dry hydrogen at 1,700
11	Aluminum oxide (Al_2O_3) and 1.0 per cent barium oxide (BaO)	1,125	Fired in dry hydrogen at 1,700
12	Beryllium oxide (BeO)	1,050	Fired in vacuum at 1,800

place, the current starts as soon as the cathode is heated again. This is a polarization effect similar to those observed in liquid electrolytes, and the transformation from the semiconductor state to the insulating state by cooling allows the storage of the charges. Cathodes of the ionic type operating with d-c bias between heater and cathode frequently suffer a sudden breakdown of the insulation, after a time, during which the resistance is almost constant or sometimes even increasing. This phenomenon is caused by ion migration. Although the leakage current is too small to form a metallic layer on the negative electrode, it is quite possible that metallic ions grow in the form of fine needles through the solid electrolyte until they bridge and short both electrodes.[1] The growth of such needles is speeded by the current concentration in front of the needle points.

The current limiting or blocking effect as mentioned in the discussion of figure 5 becomes more pronounced in cathodes which are treated at a higher temperature. The voltage-current oscillogram of such an insulator is given in figure 8. The temperature at which this oscillogram was taken was rather high in order to make the effect more pronounced in the picture. On the right side of the oscillogram, where the heater wire is positive, a large conductivity combined with a small loop is observed. With heater wire negative the current starts to rise quickly too, but at about 10 microamperes a sudden break in the curve occurs and the further rise of the current is small, linear, and reversible. The insulating action is polarized and looks somewhat like a rectification. A similar phenomenon, but occurring at the opposite polarity, is shown by figure 9.

Static measurements on cathode insulators which showed voltage-current characteristics similar to those presented in figures 8 and 9 confirmed the fact that the described break in the voltage-current characteristic is very sharp (the radius of curvature is about a tenth of a volt), and in some cases it was observed that the characteristic after the break was falling. The resistance of the insulator in the region of blocked current assumes high values, often ranging between 100 and 1,000 megohms. It sometimes surpasses the resistance of the same insulator at the same voltage in the cold state. Different thermal expansions of heater wire and cathode sleeve and change of contact pressure and area certainly are involved in this observation. At voltages higher than 200 volts (field strength of about 10,000 volts per centimeter) a sudden breakdown of the blocking action takes place at rated operating temperature, but previous conditions can be regenerated by aging at low voltage or opposite polarity.

Both cathodes presented in figures 8 and 9 consisted of pure aluminum oxide and were fired in vacuum at 1,700 degrees centigrade. Like those insulators in which an equally pronounced current blocking effect was observed they were treated at a higher temperature than those previously described cathodes which showed larger ionic conductivity. Experience seems to suggest that concentration of a certain number of ions on the border between semiconductor (hot insulator) and metallic electrode (heater wire or cathode sleeve) is responsible for the observed effect. Very intensive heat treatment (firing at more than 1,800 degrees centigrade) often destroys the blocking effect.

The oscillogram in figure 10 was taken on an insulator which was fired for 5 minutes in dried hydrogen at 1,700 degrees centigrade. The oscillogram was taken at high cathode temperature to bring the current up to easily observable values. A blocking effect on both sides of the oscillogram is visible. The insulation, except at very low voltages which can be avoided by using bias potentials, is excellent. Figure 11 presents the same insulation at a still higher temperature and shows increasing conductivity. In all these oscillograms a much more gradual break is observed for decreasing current than for increasing current.

Insulators which have had very severe heat treatment are sometimes unstable. Their voltage-current characteristic changes abruptly between a more or less proportional relation and a current limiting state. The frequency of occurrence of such changes is very irregular. It is influenced by mechanical knocks against the tube enclosure. In practice this phenomenon is called "microphonic" behavior, though it is different from the so-called microphonic insulation where chipping off of the insulating layer causes a variable galvanic contact between heater wire and cathode. Figure 12 is an example of an unstable cathode type. The time of exposure was 0.1 second (6 cycles). Two voltage-current characteristics and different sudden transitions from one into the other at different points are visible. The zero lines could not be photographed because of limitations of the shutter mechanism of the camera used.

Tubes having this microphonic behavior are very bad in radio circuits. It happens sometimes that a single microphonic tube raises the noise level of the apparatus beyond the amplitude of the audio frequency. It is believed that microphonic properties of the type described result from overheating during the firing process.

SUMMARY

Straight line voltage-current characteristics were observed only on old type cathode systems, where the whole space between heater and cathode sleeve was filled by the insulator. All modern cathodes, in which the insulation touches the cathode only at discrete points, show nonlinear voltage-current relations. If the insulating material is impure or if it is heat treated at too low a temperature, ionic conductivity and the occurrence of loops in the voltage-current oscillogram is observed. Cathodes with higher firing temperatures have reversible characteristics; cathodes fired at too high temperatures are unstable.

Under certain conditions a very pronounced current limiting or blocking effect is observed. It might be that an oxygen layer on the border between semiconductor and metallic conductor is responsible for this effect. Beyond this it is too early to advance theories. Observation of heater-cathode systems alone does not supply sufficient evidence for a complete description of the phenomenon. However, it may not be out of place to mention the cold "blocking layer" or copper oxide rectifier phenomenon,[2] whose similarity might be more than accidental. Further experiments, especially capacity and high frequency measurements, are necessary. Such investigations may lead to useful applications of heated semiconductor devices.

---

[1] For all numbered references see list at end of paper.

REFERENCES

1. UNIDIRECTIONAL IONIC AND MIXED CONDUCTIVITY IN CRYSTALS, C. Tubandt. *Zeits. f. Electrochemie*, v. 26, Sept. 1920, p. 358–63.

2. ELECTRON CONDUCTIVITY OF CUPROUS OXIDE, W. Schottky and F. Walbel. *Phys. Zeits.*, v. 34, Dec. 1, 1933, p. 858–64.

3. ELECTRICAL CONDUCTIVITY OF ELECTRON SEMI-CONDUCTORS, B. Gudden. *Ergeb. d. exakt. Naturwiss.*, v. 13, 1934, p. 223–56.

4. THEORY OF ELECTRONIC SEMI-CONDUCTORS AND THEIR POSSIBLE PROPERTIES, R. H. Fowler. Royal Soc. *Proc.*, v. 140, June 1, 1933, p. 505–22.

5. THE PRESENT THEORY OF ELECTRIC CONDUCTION, K. F. Herzfeld. ELEC. ENGG. (A.I.E.E. TRANS.), v. 53, April 1934, p. 523-8.

Impulse Voltages Chopped on Front

Problems arising from testing with impulse voltages chopped on the rising fronts of the waves are discussed in this paper. A consideration of the generation and measurement of impulse voltages is presented briefly, and the problems are studied in a discussion of the test results. The subject is treated nonmathematically and the results analyzed in terms of physical interpretation.

By
P. L. BELLASCHI
MEMBER A.I.E.E.

Westinghouse Elec. and Mfg.
Co., Sharon, Pa.

LABORATORY STUDIES of steep impulse voltages chopped on the front have been undertaken for the reason that such voltages can occur on transmission lines. Present knowledge indicates that this type of impulse appears as the result of direct strokes of lightning and on parts of the line near the point of incidence of the stroke. An important consideration of the general subject for future development will be securing more field data on the impulse voltages which appear on electric circuits as the result of lightning. In fact, it is only by a correlation of field and laboratory data that the relative value of impulse voltages chopped on the front can be established practically on a sound basis.

IMPULSE VOLTAGE GENERATION AND MEASUREMENT

The impulse voltage generator[1,2] can be represented for practical purposes by the simplified circuit of figure 1. In principle the impulse generator consists of capacitor units charged in parallel from a source of rectified alternating voltage and discharged in series by means of gaps to develop the required voltage. The wave form of the generated voltage appearing at the test load is fixed by the constants of the load and the generator, and may be controlled to a certain extent by the constants of the generator.

Representative constants for a high voltage generator when testing rod gaps, insulators, and bushings with the recommended A.I.E.E. $1^{1}/_{2}$x40 microsecond wave[4] are the following: $C_s = 8{,}000$ micromicrofarads, $L_{S1} = 60$ microhenrys, $R_s = 500$ ohms, $C_2 = 600$ micromicrofarads, and $R = 9{,}000$ ohms. In generators for medium and low voltages the value of C_s is larger and that of C_2 smaller; the other constants can be adjusted to give the recommended wave.[3]

In general, steep fronted waves cannot be obtained when large transformers are tested. Representative constants for a large power transformer are $C_T = 2{,}500$ micromicrofarads and $L_T = 0.12$ henry. Furthermore, since a lead is essential to connect the apparatus to be tested to the generator and a liberal test set-up is necessary in practical testing, the resulting lead inductance L_{S2} may approach in value the inductance L_{S1} of the generator. For these reasons fronts up to $2^{1}/_{2}$ microseconds are permissible with such transformer loads[5,6]. Experience during several years has well demonstrated the feasibility of testing practically all types of electrical apparatus with the nominal $1^{1}/_{2}$x40 microsecond wave. In such testing the impulse voltage generated is developed to the full crest value. In this method of testing, the impulse voltage can be controlled readily with full assurance by simple adjustment of the rectified alternating voltage which charges the capacitors of the generator.

When tests are made with impulse voltages chopped on the rising front, a rod gap or other suitable device is employed which chops the wave at the desired voltage value. The steepness of the front is limited by the total load capacitance in combination with the generator inductance, the lead inductance, and the series resistance. The lower these

---

A paper recommended for publication by the A.I.E.E. committee on instruments and measurements. Manuscript submitted October 31, 1935; released for publication May 19, 1936.

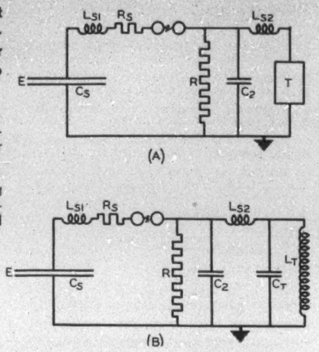
The author wishes to acknowledge the assistance of W. L. Teague and F. D. Fielder in the laboratory investigation and analysis of data.

[1] For all numbered references see list at end of paper.

Fig. 1. Circuit diagram of impulse generator connected to load

A—Load *T* may represent rod gap, insulator string, or other device

B—Load consisting of transformer represented by simplified equivalent circuit



circuit constants can be kept the greater the steepness of the front generated. The higher the impulse generator voltage is set the greater the rate of rise, but the voltage rating of the generator naturally limits the maximum steepness that can be obtained. For example, the rate of rise is of the order of 950 kv per microsecond with a load of 2,100 micromicrofarads when the impulse generator is set at full voltage (table II). This is practically twice the rate of rise that would be obtained with the impulse generator set at half voltage. The tabulation shows that for a given voltage setting of the generator the rate of rise of the generated voltage is inversely proportional to the total load capacitance.

The sphere spark gap, the resistance divider, and the capacitance divider are employed to measure impulse voltages.[7] The dividers are used in conjunction with the cathode-ray oscillograph to record the amplitude and wave form of the impulse voltage. With proper care good results can be obtained with these dividers, even when measuring impulse voltages of a fraction of a microsecond duration.[8,9] Because the sphere spark gap has limitations in measuring short impulse voltages, chiefly as the result of the impulse factor and polarity effects (table I), this device was not used for measurement in these tests.

Rod Gap Characteristic Tests

The rod gap used was mounted horizontally and conformed in its arrangement to the standard gap as defined by the transformer subcommittee of the A.I.E.E. committee on electrical machinery. It consisted of 0.5-inch square-cornered square-cut rods coaxially spaced and overhanging their supports by at least half the gap spacing, and mounted on conventional insulators giving a height above the ground plane of 1.3 times the gap spacing plus 4 inches (with a tolerance of ± 10 per cent).

Figure 2 shows the voltage characteristics of the 24 inch, 12 inch, and 6 inch standard rod gaps for rates of rise of voltage ranging from about 400 to 4,000 kv per microsecond. The long-dash curves give the average values of data published some time ago[8] for the rod gap near the generator; the short-dash part indicates extrapolation. The recent tests are shown in figure 2 as individual points to demonstrate the results that can be obtained in the generation and measurement of impulse voltages chopped on the rising front by a rod gap. These tests were made in a high voltage laboratory.

Figure 6 shows the characteristics of the 3 inch, 2 inch, and 1 inch standard rod gaps for rates of rise of voltage ranging from about 100 to 1,500 kv per microsecond. These tests were made in a medium voltage laboratory.

The oscillograms in figure 3 illustrate some of the tests made with the 24 inch rod gap. These tests were made with the gap located near the impulse generator; the small dimensions of the rod gap permit placing it closely adjacent to the generator. With the generator set to charge at 21.4 per cent of full voltage and to deliver practically a $1^1/_2$ x 40 microsecond wave, breakdown of the gap occurred on the tail of the wave as shown by oscillogram *A*, figure 3.

Upon increasing the charging voltage to 35.7 per cent, breakdown occurred at the crest of the wave, oscillogram *B*. At 82 per cent charging voltage the generated impulse is chopped by the rod gap on the

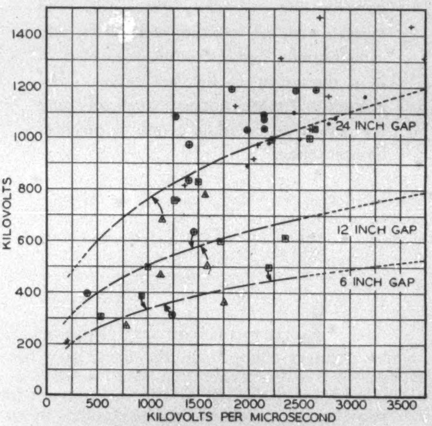


Fig. 2. Breakdown of rod gaps on rising fronts of impulse voltages

+ Rod gap near generator; positive polarity
● Rod gap near generator; negative polarity
Relative air density 0.96 to 0.97; absolute humidity 6.1 to 7.9 grains per cubic foot

⊕ Rod gap connected by 75 foot lead; positive polarity
⊙ Rod gap connected by 75 foot lead; negative polarity
Relative air density 1.02; absolute humidity 2.1 to 2.2 grains per cubic foot

Check data taken approximately 6 months later:
△ Rod gap near generator; positive polarity
⊡ Rod gap near generator; negative polarity
Relative air density 0.96 to 1.00; absolute humidity 2.5 to 4.0 grains per cubic foot

rising front, oscillogram *C*. By charging the generator to 100 per cent oscillograms *E* and *F* were obtained. These oscillograms and the corresponding data in figure 2 indicate that rates of rise of voltage up to about 3,000 kv per microsecond are obtained for the condition of no load on the generator, that is, for $C_T = 0$ in figure 1. When a substantial capacitance load is applied to the generator the steepness of the rising front is materially reduced as is indicated by the oscillograms in figure 5 and the data in table II. Another important observation from all these data is that for a given capacitance load the steepness of the rising front is practically proportional to the charging voltage, whereas the crest of the chopped impulse is fixed by the setting of the gap.

Substantial voltage drops can occur across leads when testing with steep fronted or rapidly changing impulse voltages. For example, when the 24 inch rod gap was connected to the generator through a 75 foot lead, oscillograms *G* and *H* of figure 3 show the measured voltage at the gap on successive tests and oscillogram *I* (figure 3) gives the corresponding voltage at the generator end of the lead. Inasmuch as the rod gap does not drain an appreciable current until near or at breakdown, the crest voltages of the 2 measurements are nearly the same. That is, oscillogram *H* indicates 1,035 kv and oscillogram *I* indicates 1,060 kv. The wave, however, recorded at the generator (oscillogram *I*) as compared with that recorded at the gap (oscillogram *H*) is flat on the crest and of prolonged duration. This shows that a substantial lead drop is measured at the generator upon breakdown of the rod gap, when an appreciable current flows in the lead. These tests emphasize that for correct measurement the voltage divider must be located at the rod gap or apparatus tested. The fulfillment of this requirement becomes even more important when large capacitance loads are connected through the necessary lead to the generator, as it will be seen in a discussion of the transformer tests later in this paper.

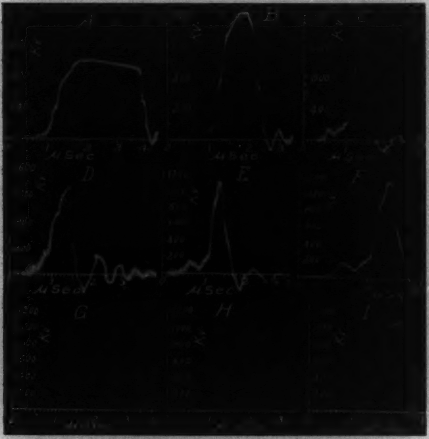


Fig. 3. Oscillograms of breakdown of 24 inch rod gap; no load on impulse generator

	A	B	C	D	E	F	G	H	I
Polarity	Pos.	Pos.	Pos.	Pos.	Neg.	Neg.	Neg.	Neg.	Neg.
Kilovolts	510	820	1310	1315	1100	1160	1035	1035	1060
Kilovolts per microsecond	(730)	(1360)	2320	1875	2440	3140	1990	2150	2350
Divider	Res.	Res.	Res.	Cap.	Res.	Res.	Res.	Res.	Res.
Voltage setting of generator in per cent of full voltage	21	36	82	82	100	100	75	75	75

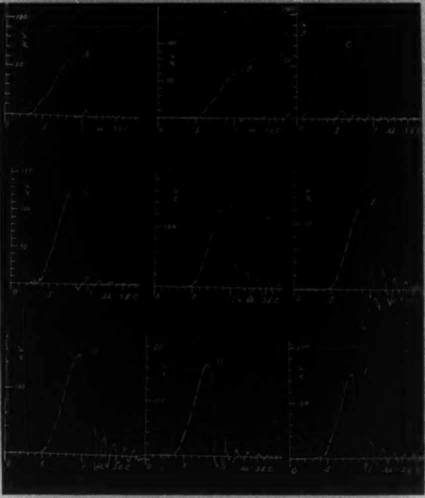


Fig. 4. Oscillograms of breakdown of short rod gaps; no load on impulse generator

	A	B	C	D	E	F	G	H	I
Gap spacing, inches	1	1	1	2	2	2	3	3	3
Polarity	Neg.	Neg.	Pos.	Neg.	Neg.	Pos.	Neg.	Neg.	Pos.
Kilovolts	58	61	71	121	128	124	160	165	154
Kilovolts per microsecond	115	135	340	335	415	430	445	460	430
Divider	Cap.	Res.	Cap.	Res.	Cap.	Cap.	Cap.	Cap.	Res.

Reproduction requirements necessitated retouching the original oscillograms of this figure

RESISTANCE AND CAPACITANCE VOLTAGE DIVIDERS

The performance of the resistance and capacitance dividers in recording steep-fronted chopped impulse voltages can be studied from the oscillograms in figures 3 and 4. In these tests the rod gap and the resistance divider were placed at the generator, since the capacitance divider is located at the generator. Oscillograms *D* and *C* (figure 3) were recorded respectively with the capacitance and the resistance dividers. They indicate closely the same crest voltage, though the corresponding rates of rise of voltage show a difference of about 20 per cent. They also differ somewhat in wave form. A comparison of the measurements of medium and low voltages with the 2 types of divider is shown in figure 4. Oscillograms *A* and *B*, *D* and *E*, and *G* and *H* indicate differences in crest voltages up to 6 per cent; the rates of rise of voltage differ up to about 20 per cent. Even before these measurements became possible all recording, control, and timing circuits, which had been fully satisfactory for standard impulse testing, had to be modified and improved materially: first, to speed up their response and recording power; second, to eliminate or dampen inherent oscillations which are so prevalant in the measurement of the very fast impulse voltages here recorded.

All considered, the experience in the use of the resistance and capacitance dividers in these and previous tests[7,8,9] establishes that these 2 types of divider are useful and desirable in high, medium, and low voltage measurements. Their judicious use has enabled the securing of dependable measurements of very short impulse voltages.

The resistance divider was found particularly useful in these tests as no 60 cycle voltage excitation was applied to the test object and the divider could be located readily at the test object. It has been established [7,8,9] and these tests have confirmed further that when very short impulses are to be recorded, the minimum number of resistor units in the divider consistent with the maximum voltage of the test and a short well-insulated cable from the divider to the oscillograph are the best assurances of good performance. These requirements were met as follows: The resistance of the divider was limited to between 10,000 and 17,000 ohms when measuring voltages from about 500 to 1,500 kv (figure 2), and to 3,000 ohms when measuring voltages below 200 kv (figure 6). For dependable results a 500 foot cable, that was satisfactory for the measurement of long voltage waves, had to be reduced to 75 feet, the minimum length required to connect the divider at the test object to the cathode-ray oscillograph. Another important consideration is the location of the cable over the ground. Unless the cable is kept removed from the ground discharge path of the generator, high extraneous voltages may be set up in the cable with resultant errors entailed in the measurement.

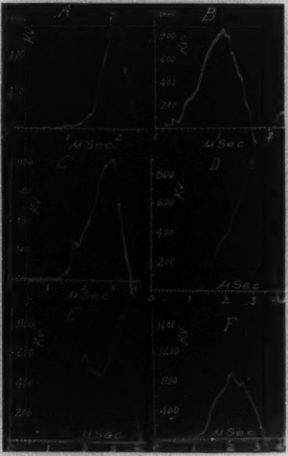


Fig. 5. Oscillograms of breakdown of rod gaps; transformer load on impulse generator

	A	B	C	D	E	F
Gap spacings, inches	12	24	24	24	24	24
Polarity	Pos.	Neg.	Pos.	Pos.	Pos.	Pos.
Kilovolts	640	855	835	895	860	885
Kilovolts per microsecond	1450	1220	695	640	665	985
Divider	Res.	Res.	Res.	Res.	Res.	Res.
Total load capacitance, micromicrofarads	1000	1000	1700	2100	2100	2100
Voltage setting of generator in per cent of full voltage	50	50	50	57	57	100

Table I—Comparison of the Spark-Over of Sphere Gaps on the Rising Front for Different Rates of Voltage Rise

Sphere Diameter, Centimeters	Separation in Per Cent of Sphere Diameter	Ratio of the Spark-Over on the Front of the Wave for Different Rates of Rise to the Spark-Over at 2.0 Microseconds Duration							
		Rate of Rise in Kilovolts per Microsecond							
		31.25	62.5	125	250	500	1,000	2,000	4,000
Positive polarity									
6.25	16	1.12	1.32	1.57	1.71				
	32	1.00	1.08	1.20	1.35				
	64		1.00	1.10	1.27	1.41			
25	16		1.00	1.11	1.23	1.31	1.36		
	32		1.00	1.01	1.09	1.17	1.24		
	76			1.00	1.01	1.08	1.17		
200	4			1.00	1.02	1.19	1.38	1.66	
	8				1.00	1.03	1.15	1.33	1.50
	16					1.00	1.03	1.17	1.31
	32						1.00	1.03	1.11
Negative polarity									
6.25	16	1.12	1.32	1.53	1.70				
	32	1.00	1.10	1.27	1.42				
	64	1.00	1.01	1.12	1.29	1.46			
25	16		1.00	1.16	1.34	1.50	1.62		
	32		1.00	1.01	1.11	1.22	1.32		
	64			1.00	1.04	1.16	1.32		
200	4			1.00	1.02	1.23	1.49	1.74	
	8			1.00	1.01	1.08	1.24	1.45	1.65
	16				1.00	1.01	1.07	1.21	1.37
	32						1.00	1.05	1.17

After these difficulties and inherent errors in the measurement were reduced to a practical minimum by a systematic process of elimination, dependable measurements could be obtained. Oscillograms *G* and *H* in figure 3 were taken with exactly the same generator and measurement set-up a few minutes apart. They are practically identical. Another example is given by oscillograms *E* and *F* (figure 3). These also were taken with practically an identical set-up but at a considerable time interval apart. The voltages in this case differ 6 per cent and the rates of rise about 25 per cent.

Besides the variation in the voltage measured, errors are encountered in measuring the time and in the scaling of the oscillograms. The errors in scaling affect particularly the determination of the rate of rise of voltage. This variation is inherent in the scaling since the front is often of varying shape and slope, and therefore the equivalent slope is then a matter of definition and judgment. This variation can be reduced in some measure by the use of liberal timing scales, but practical requirements in synchronizing the cathode beam, the timing circuit, the generation of the impulse voltage, etc., limit the fastest time scale that can be used. The time scales of the oscillograms of figures 3, 4, and 5 are liberal. Although the technique of generating and measuring steep-fronted chopped impulse voltages is an extension of the methods applied in the standard impulse voltage testing,[5,6] considerably greater tolerances appear necessary. The voltage variation in generation cannot be great, but the combined errors in the measurement and the inherent variation in the breakdown of the rod gap or similar device indicate an over-all spread in the results of from 10 to 20 per cent. When all the data of the rod gaps in figures 2 and 6 are considered, the spread between some of the scattered points is even greater than 20 per cent.

IMPULSE VOLTAGES CHOPPED BY SPHERE GAP ON RISING FRONT

An investigation of the spark-over of the 6.25, 25, and 200 centimeter sphere gaps on the rising front of steep impulse voltages has already been reported.[9] Table I summarizes the data. These indicate the following: (*a*) the impulse ratio of the spark-over voltage increases with the steepness of the front; (*b*) on the basis of separation expressed as per cent of sphere diameter, the impulse ratio is greater for the smaller than for the larger spheres; (*c*) the impulse ratio for the negative polarity of the voltage exceeds somewhat that for the positive, but practically the difference is not significant.

The tabulation gives average data. Individual values indicate variations, the scattering being greatest for the very short impulse voltages of from 0.3 to 0.2 microsecond duration. Even then the variation does not seem to be as great on the whole as for the rod gap.

TESTS WITH ELECTRICAL APPARATUS LOAD CONNECTED TO IMPULSE GENERATOR

Electrical apparatus such as insulators, line-insulator protectors, and lightning arresters, because of its relatively small capacitance, does not present problems different from those encountered in testing rod and sphere gaps. The breakdown path of such apparatus is essentially that of an air gap. Unless special measures such as pre-ionizing or field control are taken, the impulse characteristics of rod and sphere gaps in figure 2, figure 6, and table I are indicative of the limits of the wide range of characteristics this electrical apparatus can assume.

Transformers, bushings, and similar apparatus impose a large capacitance load on the generator. The oscillograms in figure 5 and the data in table II illustrate the effect on the generated impulse voltage produced by representative high voltage power transformers. The total load capacitance in these tests ranged from about 1,000 to 2,500 micro-microfarads. The test data show that for a given voltage setting of the generator and fixed generator constants the rate of rise of the applied impulse voltage is inversely proportional to the total load capacitance. This relation can be demonstrated readily by analysis. The steepest rate of rise which is obtainable with the impulse generator alone

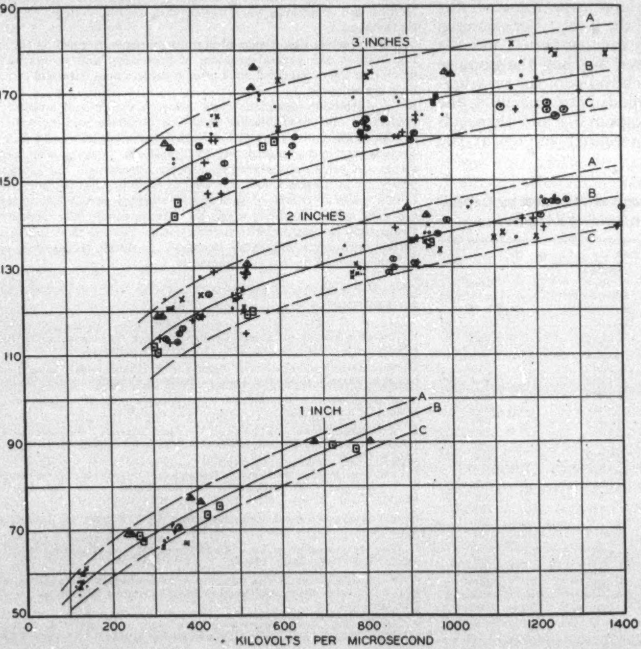


Fig. 6. Breakdown of short rod gaps on rising fronts of impulse voltages

A, *B*, and *C* are maximum, average, and minimum values, respectively

First set of data—relative air density 0.96 to 0.98; absolute humidity 3.4 to 5.3 grains per cubic foot

× Negative polarity; resistance divider

+ Positive polarity; resistance divider

● Negative polarity; capacitance divider

⊙ Positive polarity; capacitance divider

Check data 6 months later—relative air density 0.97 to 0.98; absolute humidity 2.5 to 3.3 grains per cubic foot

⊡ Positive polarity; capacitance divider

△ Negative polarity; capacitance divider is reduced to a fourth or even less when a large capacitance load is connected to the generator. For the total load of 2,100 micromicrofarads, even with the generator charged to full voltage, the rate of rise attained was less than 1,000 kv per microsecond, as oscillogram *F* of figure 5 and table II show.

The crest value of the impulse voltage is controlled by the rod gap setting. The oscillograms *A* and *B* in figure 5 correspond to tests with the load capacitance of 1,000 micromicrofarads. In this case the generator was charged to 50 per cent, thus fixing the rate of rise of the voltage to an average of 1,300 kv per microsecond. With the rod gap set at 12 inches the crest voltage was limited to 640 kv (oscillogram *A*) and on increasing the spacing of the rod gap to 24 inches the crest voltage was accordingly increased to 855 kv (oscillogram *B*). Oscillogram *A* indicates a somewhat greater rate of rise than oscillogram *B;* but this is because the 12 inch gap chopped the wave on the steeper part of the rising front, and in scaling oscillograms the average effective slope is traced.

Voltage drops in leads become pronounced with large capacitive loads. Oscillograms *D* and *E* in figure 5 illustrate this. The measurements were made using the resistance divider since no 60 cycle voltage was applied and the divider could be located at the transformer. The first oscillogram is measured at the transformer and the second at the generator end of the lead. It is apparent that a large voltage drop occurs in the lead which is the result of the heavy current drain of the large capacitance of the load during the rising part of the front. For example, if in the tests represented by oscillograms *D* and *E* a 6 inch rod gap had been used to chop the impulse voltage instead of the 24 inch rod gap, the measurement at the generator would have included the large lead overshoot (oscillogram *E*) and then collapsed. In this case the measured voltage at the generator would have shown approximately 100 per cent greater voltage and more than 100 per cent greater rate of rise than that measured at the test object. This example illustrates an extreme case, but emphasizing, however, the difficulty in measurement from voltage drops when testing with steep-fronted chopped impulse voltages.

Table II—Rate of Rise of Voltage as Affected by Capacitance of Load; Rod Gap Spacing 24 Inches

Voltage Setting of Impulse Generator in Per Cent of Full Voltage	Total Load** Capacitance, Micromicrofarads	Rate of Rise, Kilovolts per Microsecond	Crest Voltage, Kilovolts
50	600	2,080	976
		1,980	892*
		2,040	919
		1,950	960
50	1,000	1,400	975
		1,400	975
		1,370	965
		1,240	990
		1,270	1,017
		1,240	998
		1,220	855*
50	1,700	655	730
		650	725
		690	745
		750	733
		675	823
100	2,100	985	885
		970	870
		955	860*
		920	825*

* Negative polarity; all others are positive.

** The total load consists of the stray capacitance of the impulse generator (600 micromicrofarads) and a transformer.

The test values of the oscillograms in figure 5 and in table II for the various loads when compared with the data in figure 2 for the condition of no load indicate that general agreement exists in the over-all average data. These data of the rod gap breakdown voltage with load on the generator show the same amount of variation as for the rod gap tested with no load on the generator. These tests emphasize again that in testing with steep-fronted chopped impulse voltages considerably greater tolerances in variation of the voltage and duration were found necessary than would have been permitted in the regular testing with long impulse voltage waves.

SUMMARY

1. Impulse voltages chopped on the rising front are much more difficult to produce, control, and apply than the fully developed waves.
2. Their measurement is subject to greater errors.
3. Compared with the present practical technique of testing with fully developed waves considerably greater tolerances are required.
4. The experiences and data presented here on impulse voltages chopped on the rising front relate to experimental testing. With other laboratory experiences and field data they form a factual basis for further discussion and consideration of the relative merits, limitations, and drawbacks when testing with impulse voltages chopped on the front.
5. The relative significance of impulse voltages chopped on the rising front in the general problem of protection and co-ordination cannot be fully evaluated until more complete field data and experience are obtained.
6. A distinction should be made between the general problem of protection and co-ordination, and the objective and purpose of commercial impulse testing. Such commercial tests should aim to demonstrate in a practical way the fulfillment of specified requirements and are an acceptance test on the apparatus. For example, protective apparatus would be tested to establish that the apparatus fulfills certain criteria of protection, whereas substation apparatus, such as transformers, would be tested commercially to demonstrate that the insulation structure meets the specified insulation level. Such tests should be practical, as simple as possible, and demonstrate the desired requirements.

REFERENCES

1. CHARACTERISTICS OF SURGE GENERATORS FOR TRANSFORMER TESTING, P. L. Bellaschi. A.I.E.E. TRANS., v. 51, Dec. 1932, p. 936–45.

2. IMPULSE GENERATOR CIRCUIT FORMULAS, J. L. Thomason. ELEC. ENGG. (A.I.E.E. TRANS.), v. 53, Jan. 1934, p. 169–76.

3. THE PRODUCTION OF IMPULSE TEST VOLTAGES, C. S. Sprague. ELEC. ENGG. (A.I.E.E. TRANS.), v. 54, October 1935, p. 1100–04.

4. RECOMMENDATIONS FOR IMPULSE VOLTAGE TESTING. A report by the A.I.E.E. lightning and insulator subcommittee, A.I.E.E. TRANS., v. 52, June 1933, p. 466–71.

5. PROGRESS REPORT ON IMPULSE TESTING OF COMMERCIAL TRANSFORMERS, F. J. Vogel and V. M. Montsinger. A.I.E.E. TRANS., v. 52, June 1933, p. 409–10.

6. RECOMMENDED TRANSFORMER STANDARDS, H. V. Putnam and J. E. Clem. ELEC. ENGG. (A.I.E.E. TRANS.), v. 54, Dec. 1934, p. 1594–7.

7. THE MEASUREMENT OF HIGH SURGE VOLTAGES, P. L. Bellaschi. A.I.E.E. TRANS., v. 52, June 1933, p. 544–52.

8. FACTORS INFLUENCING THE INSULATION CO-ORDINATION OF TRANSFORMERS—II, P. L. Bellaschi and F. J. Vogel. ELEC. ENGG. (A.I.E.E. TRANS.), v. 54, June 1934, p. 870–6.

9. SPHERE-GAP CHARACTERISTICS ON VERY SHORT IMPULSES, P. L. Bellaschi and W. L. Teague. *Elec. Jl.*, v. 32, March 1935, p. 120–3.

Electrical Measurement of Silk Thread Diameter

Continuous measurement of the diameter of silk thread may be made and recorded by the apparatus herein described, which depends for its operation on changes in capacitance as variations in thread diameter move the jaws of a caliper. From the record the quality of the fabric may be predicted closely, and by the addition of integrating devices a numerical reading for quality rating may be obtained at the end of a run. The applications of the measurement in the control of knitting, limit testing, and quality rating are discussed, and the results of comparisons with present methods of rating the quality of raw silk yarn are given.

By
O. HUGO SCHUCK
ASSOCIATE A.I.E.E.

Univ. of Pennsylvania,
Philadelphia

THE apparatus described in this paper was developed in the course of an investigation to determine the possibility of utilizing electrical means in the measurement of silk thread for purposes of testing and control in the silk hosiery industry. In its adaptation to this field, the apparatus illustrates a novel application of the use of electrical measurements for the measurement of nonelectrical quantities.

A brief review of the processes normally used in the manufacture of silk hosiery may be helpful to those readers not acquainted with this industry. The raw silk thread, consisting of from 3 to 5 silkworm filaments twisted lightly together and held together by the natural gum, arrives from Japan in skeins packed in bales. Acceptance tests including tests for size, strength, elasticity, cleanness, and evenness are made on samples from each bale. For testing the latter 2 properties, the "seriplane test" has been extensively used. In this test the thread is machine wound on broad black panels and compared under standardized illumination with standard sample panels.

For testing evenness more precisely, the "composite 9 meter evenness test"[1] is coming into wide use. From sample skeins selected from the 10 bales of each lot are cut 50 lengths of thread 2,250 meters long and 500 lengths 9 meters long. These lengths are weighed individually and the results are treated statistically to give a measure of long length and short length evenness. This test is quite sensitive and accurate in predicting the percentage of evenness rejects in the finished stockings, and is important because the ringed and banded appearance of stockings knitted with uneven thread is especially disliked by women.

After acceptance, the skeins are wound onto spools which are placed on the twisting machine, where from 2 to 15 threads, depending upon the desired weight of the stocking, are twisted together to form the yarn for knitting. Since the yarn leaves the twisting machine on a flanged spool, it is necessary to rewind it on a cone winding machine onto a cardboard cone from which it is fed into the knitting machine. Various other processes, such as soaking, tinting, degumming, dying, etc., have not been included in the above sequence because of variations with different manufacturers and unimportance to the present purpose.

A study of the processes just outlined and of the factors influencing the quality ratings of the raw silk thread, the twisted yarn, and the finished fabric led to the conclusion that the measurement of the diameter of the thread was of primary importance. Apparatus of the ultramicrometer type was developed capable of measuring continuously the diameter of a running thread with a high order of accuracy and reliability, and tests were made to determine the value of the measurements. The technical features of the apparatus and the results obtained will be described in the following.

MEASURING SYSTEM

The first necessary development was that of a sensitive and stable measuring system. This comprised a thread caliper and the associated electrical means for measuring its displacement. In figure 1 is shown a schematic cross section of the caliper. The thread passes between a stationary and a movable caliper jaw, each having plane faces, so that their separation is determined by the diameter of the thread. Fastened to the arm carrying the movable jaw is one plate of an electrical capacitor the other plate of which is fixed, so that the spacing of the plates and therefore the capacitance is determined directly by the diameter of the thread.

The caliper capacitor is a part of the total capacitance of a tuned circuit in which is induced a constant voltage from a high frequency oscillator. As the capacitance is varied the voltage across the inductance of the tuned circuit varies, and by working on one side of the resonance curve the variation of voltage with capacitance and therefore with thread diameter is large and linear over a certain range, as shown in figure 2. This is the usual form of ultramicrometer device. However, this simple circuit is very sensitive to small changes in frequency and amplitude of the applied voltage. Figure 3 shows the

---

A paper recommended for publication by the A.I.E.E. committee on instruments and measurements. Manuscript submitted December 30, 1935; released for publication March 3, 1936.

[1] For all numbered references see list at end of paper.

effect of a change in amplitude: the voltage V_1 increases to V_1', giving a false indication corresponding to a change in capacitance to C_2 with constant amplitude of applied voltage. Similarly, figure 4 shows the effect of a change in frequency: the resonance curve changes from the solid to the dotted line and the voltage V_1 decreases to V_1', giving a false indication corresponding to a change in capacitance to C_3 with constant frequency of applied voltage. As indicated by figures 3 and 4, a change in amplitude of the applied voltage can be compensated for by a simultaneous change in its frequency of the proper sense and magnitude. This is the basis of the apparatus developed by Field.[2] It will be recognized that temperature changes can produce effects similar to those described above through the resultant changes in the constants of the tuned circuit.

From these considerations the use of a null method is indicated. The circuit used is shown in figure 5. The type 57 tube acts as an electron-coupled oscillator, with its work anode circuit inducing equal electromotive forces in the identical inductors L_1 and L_2. Inductor L_2 is tuned by capacitor C_2 to a frequency slightly below that generated by the oscillator so that the conditions shown in figure 2 are obtained. Inductor L_1 is similarly tuned by the caliper capacitor C_1', the compensating capacitor C_1'', and the zero adjusting capacitor C_{1a}. The voltages across C_1 ($C_1 = C_{1a} + C_1' + C_1''$) and C_2 are applied respectively to the grids of the type 56 tubes V_1 and V_2 whose plate circuits form 2 arms of a bridge circuit of which the other 2 arms are R_{L1} and R_{L2}. When C_1 is equal to C_2, the voltages across them are equal. An unbalance in the bridge due to unequal voltages across C_1 and C_2 causes the galvanometer relay to close the circuit to one of the power relays operating the reversible motor, which changes C_1'' until equality of voltages is restored and C_1 again equals C_2. Changes in the capacitance of the caliper capacitor C_1' due to variations in the thread diameter are thus automatically and continuously compensated for by the compensating capacitor C_1'', and the angular position of C_1'', which is of the rotary type used in tuning the circuits of radio sets, becomes a measure of the thread diameter. By suitably shaping the plates of C_1'', any desired scale law may be obtained. A pointer coupled to the compensating capacitor shaft indicates the diameter on a scale, while a pen controlled by the same shaft moves transversely across a chart whose longitudinal speed is proportional to the speed of the thread passing through the caliper capacitor so that a record of diameter as a function of length is obtained.

It may be seen that small changes in amplitude or frequency of the oscillator output will have no effect upon the indication, since both tuned circuits are affected equally, and the electrical circuits are used solely for the purpose of maintaining the equality of the capacitance of C_2 and the total capacitance of C_1. Temperature changes will likewise affect both inductors equally, since they are identical in size and shape. Only changes in the characteristics of the vacuum tubes V_1 and V_2 can affect the indication, and since these tubes are chosen for equality of plate characteristics, the changes in operation are small. In apparatus developed later and described in another section of this paper, the effects of changes in the tube characteristics are practically eliminated. In making the tests described here one point on the scale was checked against a standard thickness gauge at the beginning and at the end of each run, which usually lasted about 20 minutes, and the drift was found to be negligible during this time. Checks against these gauges indicated an accuracy of about ±0.00003 inch.

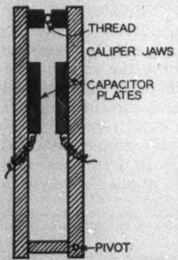


Fig. 1. Cross-sectional diagram of caliper capacitor

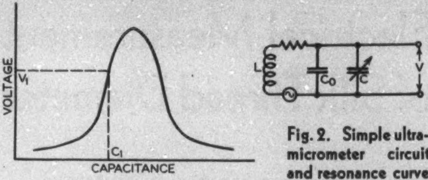


Fig. 2. Simple ultramicrometer circuit and resonance curve

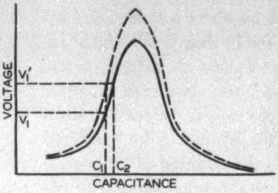


Fig. 3. Curves illustrating effect of a change in amplitude of applied voltage

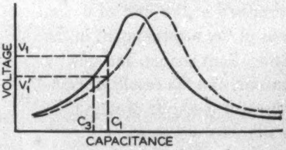


Fig. 4. Curves illustrating effect of a change in frequency of applied voltage

Possibility of Extended Applications

Although in the apparatus just described the motor is used only to move the compensating capacitor and recording pen, it can also be made to perform other tasks. It was thought that it could automatically control the loop length of the knitting machine, appropriately shortening the loop as the yarn became thinner in order to give an even appearance to the finished fabric. Inspection of specially knitted fabric having various loop lengths showed that such compensation was possible if the variations in diameter were not too large. However, the expense of accomplishing this result was considered too great, since it involved the installation of a complete measur-

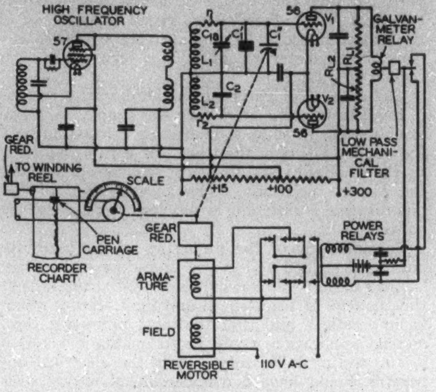


Fig. 5. Schematic diagram of apparatus arranged for continuous recording of thread diameter

ing and controlling apparatus for each knitting position, and furthermore introduced difficulties in maintaining the proper total length of stocking.

A second application was indicated by the thought that an improvement could be made in the fabric if those parts of the yarn having diameters larger or smaller than certain fixed limits could be completely removed. The yarn was measured as it was being wound onto the cardboard cones on the cone winding machine, a separate measuring unit being contemplated for each spindle. The first arrangement utilized upper and lower limit contacts operated by the shaft of the compensating capacitor, the closure of either contact operating a relay to disengage and stop the spindle. This arrangement was capable of stopping the cone winding machine running at its full motor speed of 1,200 rpm in response to an out-of-limit length of yarn of about 10 yards, the accuracy being about one per cent.

In an effort to reduce the length of out-of-limit yarn necessary to stop the cone winding machine, a modification departing from the strict null method arrangement of the original circuit was employed, as shown in figure 6. Here the galvanometer relay is fitted with a stiffer spring and limit contacts. While not as inherently stable, this arrangement is capable of much greater speed of operation, and its use enabled stopping of the cone winding machine on an out-of-limit length of yarn of less than 2 yards.

An interesting feature of this arrangement is necessitated by the variability characteristics of the thread. In knitting hosiery, a thick or thin length in the thread will not be apparent in the finished stocking unless it is long enough for 2 or 3 courses, that is, about a yard and a half long, and the apparatus must discriminate selectively against out-of-limit lengths shorter than this. Since the thread runs through the caliper at a fairly constant speed, time characteristics are used, and the insertion of a specially designed low-pass mechanical filter between the galvanometer movement and the contacts eliminates the effects of variations less than about a yard and a half in length. The construction of this mechanical filter is shown in figure 7, together with its electrical analogue. From the figure it may be seen that the motion of the galvanometer coil against its restoring spring is communicated through the compliance of the coupling reed to the inertia wheel, which is mounted on jeweled bearings and carries the contact studs. The operation of this arrangement in smoothing out high speed fluctuations is readily apparent. A similar low-pass mechanical filter is used in the galvanometer relay of the measuring apparatus as arranged for recording, as shown in figure 5, to eliminate the contact chatter caused by diameter variations in short lengths.

It was found that the amount of labor required to remove the oversize and undersize yarn and to tie the ends together was too large with most yarns to give this application much promise.

The third application investigated was the adaptation of the apparatus for testing and evaluating the quality of raw silk thread and yarn by a determination of its evenness. The apparatus as arranged for continuous chart recording was used. In order to obtain a numerical result, the records were analyzed by mechanical-mathematical means, it being planned that in a device built expressly for the purpose of quality determination, the taking of a record and its subsequent analysis by hand would be replaced by the action of mechanical devices giving directly a numerical result at the end of a run.

A study of the composite 9 meter evenness test indicated that a comparable measure of the evenness would be the average squared deviation of the diameter from the mean diameter. The average diameter was found from the record by the use of a planimeter, and the average squared deviation was found by the use of a specially designed ordinate-squaring device used in conjunction with a standard planimeter. The latter performed the integrating function, but the ordinate-squaring function required the design and construction of a unique mathematical instrument which is shown diagrammatically in figure 8.

In this instrument the carriage moves on a track parallel to the axis of the curve while the tracing point arm and planimeter point socket arm move perpendicularly to the axis. The motion of the trac-

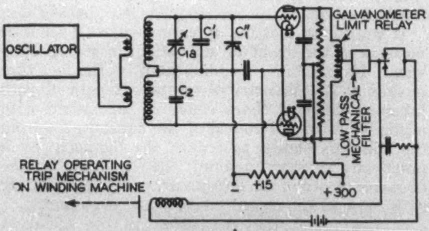

OSCILLATOR
C1a
C1'
C1''
C2
GALVANOMETER LIMIT RELAY
LOW PASS MECHANICAL FILTER
RELAY OPERATING TRIP MECHANISM ON WINDING MACHINE
−
+15
+300

Fig. 6. Schematic diagram of high speed apparatus for limit testing

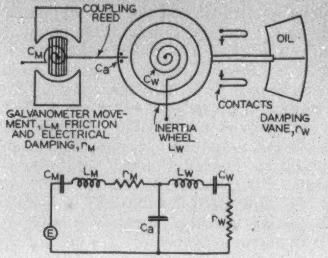


Fig. 7. Diagram of low pass mechanical filter and its electrical analogue

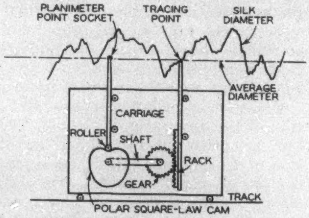


Fig. 8. Schematic diagram of ordinate squaring device

ing point is transformed by the rack and gear into rotation of the polar square-law cam, causing motion of the planimeter point socket arm through the roller which bears on the cam. The planimeter point traces a curve whose length is the same as the length of the original curve, but whose ordinates are the squares of the ordinates of the original curve with reference to the mean diameter. Division of the planimeter reading by the length of curve traced gives the average squared deviation for the length of thread measured. The average of these results for the number of lengths of thread tested gives a quality rating for the lot.

Reliability of Measurements and Their Application

In collaboration with E. N. Ditton of the Gotham Silk Hosiery Company, a number of tests were devised and carried out by the author to determine the reliability of the results obtained, and the correlation of these results with the appearance of the finished fabric.

It was found that the apparatus gave an accurate measure of the diameter and weight of silk knitting yarn. Its reliability was indicated by the fact that records of the diameter of the same length of yarn taken at different times could be superposed with negligible error. Removal of the natural gum from the silk was shown to reduce the diameter by a practically constant amount, the variations in the diameter record of the degummed yarn still matching with those in the record taken before degumming.

It was found that variations in the apparent density of the knitted fabric, such as rings and bands, were directly dependent upon the diameter of the yarn. In fact, the relative variations in yarn diameter could be predicted from visual examination of the knitted fabric and be found to check very closely with the diameter record of the yarn made after raveling the fabric.

The amount of variation in the diameter records of raw silk thread and of yarn was found, on casual examination, to show a qualitative correlation with the quality rating of the thread or yarn as obtained by the standard tests, the lower quality silk showing the larger variations. The investigation of the quantitative correlation is discussed in a following paragraph.

Consideration of the properties of the basic apparatus described and of the procedure in handling silk in a hosiery mill has indicated that at the present time control of loop length and limit testing would be impractical, and that the most promising commercial application would be to quality evaluation in the testing laboratory. Here the electrical apparatus would have a commercial advantage over the present test methods in not destroying the silk tested, in avoiding sampling errors, and in requiring less labor.

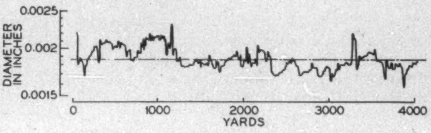


Fig. 9. Example of record of thread diameter

Winding speed 300 yards per minute; $M = 0.00187$ inch; $\sigma^2 = 0.0760$ square inch

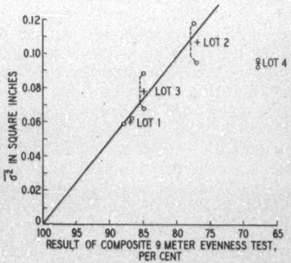


Fig. 10. Curve showing results of tests with electrical apparatus plotted against results of composite 9 meter evenness test

In order to determine the correlation between the standard silk tests and that performed by the electrical apparatus, arrangements were made for the testing of 4 lots of raw silk thread, each consisting of 2 parts. The results of a composite 9 meter evenness test and a seriplane test were obtained for each part, and diameter records were made of a number of lengths from each part. From lot 1 and lot 2, 25 lengths of 4,000 yards each were recorded in each part; from lot 3 and lot 4, 20 lengths of

6,000 yards each were recorded in each part. A sample record is shown in figure 9.

The records were analyzed as outlined previously, finding for each part the average diameter and the average squared deviation. The latter is plotted against the result of the composite 9 meter evenness test in figure 10. It may be seen that the results of the tests on lot 1, lot 2, and lot 3 indicate a linear relationship, but that the result of the test on lot 4 is definitely off the curve. It may be noted that the 2 parts of lot 4 gave very consistent results for the electrical test, indicating a high order of reliability. The results of the composite 9 meter evenness test and of the seriplane test checked better between themselves for this lot than for any of the others, indicating reliability for the standard methods. Considerably extended comparative tests will be required to determine completely the correlation with the standard tests and the accuracy of the electrical apparatus in predicting the yield in finished stockings.

IMPROVED APPARATUS WITH INTEGRATING DEVICES

Since the tests described have shown that the average squared deviation of the diameter is a suitable measure of quality, the need is indicated for apparatus which will perform the required squaring and integrating functions while the thread is being run through the caliper, and which will at the end of a run give numerical readings from which the quality rating may be obtained immediately. Such apparatus has been designed and its construction has been begun.

In figure 11 is shown a schematic drawing of the new apparatus. The caliper and caliper capacitor and the compensating capacitor are substantially unchanged, but the electrical circuits, while operating in the same manner, utilize improved forms of rectifier and motor control means. The vacuum tube bridge arms in figure 5 operate as plate circuit rectifiers and therefore depend for stability upon the stability of their mutual characteristics. By using diode rectifiers with high load resistances, greatly increased independence of vacuum tube characteristics is achieved. However, more power is required from the high frequency oscillator. The relays controlling the reversing motor are replaced by 2 grid-controlled gaseous rectifier tubes. Since all moving mechanical contacts are thus eliminated, the low-pass mechanical filter is not needed to prevent contact chattering, and since its length-selective effect is obtained through the time constants of the rectifier circuits, it may be eliminated completely.

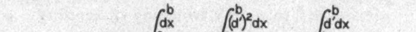


Fig. 11. Schematic diagram of quality rating apparatus

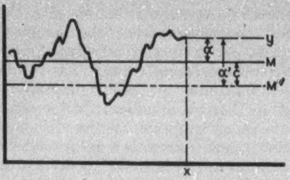


Fig. 12. Relationship of quantities used in statistical analysis of variability of a continuous function

Instead of connecting the compensating capacitor to a recording mechanism and subsequently analyzing the record, it is connected directly to integrating devices from which the quality rating may be obtained immediately upon the completion of a run. In order to explain the operation of these integrating devices it will be well to digress for a moment to state mathematically certain equations adapted from the theory of the statistical analysis of discrete observations[3] to the analysis of a continuous function. Reference may be made to figure 12.

Let $y = f(x)$ be a continuous function. (Here y is the diameter of the thread as a function of its length between the x limits a and b.)
M = mean value of the function. (Here the average diameter)

$$d = y - M \tag{1}$$

(deviation of the diameter from the mean, M)

$$\sigma^2 = \frac{\int_a^b d^2 dx}{\int_a^b dx} \text{ (mean square deviation from the mean, } M\text{)} \tag{2}$$

Let M' equal an assumed value of M; the error C in assumed value of M is

$$C = M - M' \tag{3}$$

$$d' = y - M' \text{ (the deviation from the assumed mean, } M'\text{)} \tag{4}$$

$$s^2 = \frac{\int_a^b (d')^2 dx}{\int_a^b dx} \text{ (mean square deviation from the assumed mean, } M'\text{)} \tag{5}$$

$$C = \frac{\int_a^b (d') dx}{\int_a^b dx} \tag{6}$$

$$\sigma^2 = s^2 - C^2 \tag{7}$$

Equation 7 states that the mean squared deviation from the true mean can be found from the mean squared deviation from an assumed mean and the error in this assumed value of the mean. Two integrators are therefore required, one to give the integrated squared deviations from the assumed mean and the other to give the integrated first power deviations from the assumed mean. The values s^2 and C^2 can then be found by use of equations 5 and 6, the length $\int_a^b dx$ being indicated by a yardage counter. Both integrators are of the disc and wheel type, the linear and square law relationships being obtained by means of suitable polar cams geared to the shaft of the compensating capacitor.

The construction of the compensating capacitor is such that a linear diameter scale is obtained. This has been done so that the operations employed in reducing the observations of the 9 meter test may be simulated exactly and the effect of the various factors determined with a view toward simplification of the necessary computation. The quality rating similar to that obtained by the 9 meter test is

$$R_9 \text{ (per cent)} = \left(1 - \frac{\sigma^2}{M + \sigma^2}\right) 100 \tag{8}$$

the quantities involved being expressed in microns and the dimensional inequivalence being ignored. This formula is sanctioned by usage and was orginally adopted because its results seemed to give the best correlation with observed yields of fabrics. It may be found as a result of further tests that the most simple formula

$$R_{d0} \text{ (per cent)} = (1 - \sigma^2)100 \tag{9}$$

or, the theoretically more satisfactory formula

$$R_{d2} \text{ (per cent)} = \left(1 - \frac{\sigma^2}{M^2}\right) 100 \tag{10}$$

can be used. In any case it is possible to construct a nomogram to carry out the necessary computation in a few seconds, although direct computation with a slide rule takes but little longer. The determination of the most useful rating formula must naturally await the completion of the new apparatus and extensive comparative tests made with it on both raw silk thread and spun yarn.

In the present routine testing of silk thread, measured lengths are weighed to determine the average weight and therefore the average diameter. It may be noted that the determination of the average diameter M as described above give the same result, so that the weighing test may be eliminated. Conversely, if it is found that the weight gives a sufficiently accurate measure of the average diameter, the first-power integrator may be eliminated.

Since the apparatus is to be used in the silk mill, in the physical design due attention has been given to reliability, ease of maintenance, and ease of operation. Only 60 cycle a-c power is required, while vacuum tubes are of readily obtainable types, and being used below ratings and in circuits such that small changes in characteristics do not affect operation, should give long service. All adjustments and circuit tests may be made from the front panel.

As is usual practice in the silk mill, one operator must be able to attend a number of machines. This requires the incorporation of a set of contacts held closed by the thread tension and arranged to stop the machine without error in the integrators when the thread breaks.

REFERENCES

1. NINE METER SIZINGS AS A MEASURE OF EVENNESS, W. P. Seem. *Textile World*, v. 79, 1931, May 2, 1931, p. 2014, and May 9, 1931, p. 2126.

2. R. F. Field. U. S. Patent No. 1,813,488.

3. See for example STATISTICAL METHODS (a book), F. C. Mills. Henry Holt and Co., N. Y., 1924.

A New Telephotograph System

Transmission of photographs over telephone wires was begun commercially several years ago, but recent improvements have increased to 11 by 17 inches the size of photograph that could be transmitted and have made it possible for the picture to give much more information. The new machines used for sending and receiving photographs are described in this paper, and the requirements and control of the wire system necessary to prevent imperfections in the picture and to permit switching of sending and receiving stations are discussed.

By
F. W. REYNOLDS
Member American Physical Society

Bell Tel. Labs., Inc.,
New York, N. Y.

A TELEPHOTOGRAPH message service between New York, Chicago, and San Francisco was initiated in April 1925 by the Bell System, and was extended during the following 2 years to 5

A paper recommended for publication by the A.I.E.E. committee on communication, and scheduled for discussion at the A.I.E.E. South West District meeting, Dallas, Texas, Oct. 26–28, 1936. Manuscript submitted June 16, 1936; released for publication July 30, 1936.

The attainment of this objective in telephotograph development and the establishment of the present leased wire network has engaged the initiative and resourcefulness of several score of individuals at the Bell Telephone Laboratories, Inc., the Western Electric Company, and the American Telephone and Telegraph Company. In reviewing the advances which have been made, the practical limitation of space has made it impossible to discuss in greater detail the various phases of the work and to render individual recognition to all who have contributed to the solution of the problems involved. Among those most intimately concerned and through whose efforts the many details have been worked out and correlated are W. A. Phelps and P. Mertz of the Bell Telephone Laboratories, Inc., and I. E. Lattimer of the American Telephone and Telegraph Company.

additional cities. Experience in the operation of this service, using equipment previously described,[1] indicated that a number of improvements were desirable in order to meet more satisfactorily the apparent requirements of this form of communication. Developmental work was undertaken to effect these improvements, and this paper describes the new equipment and some of the features involved in establishing a leased wire telephotograph network connecting 26 cities as shown in figure 1.

During the 8 years of operation of the first Bell System telephotograph service the performance of the system was observed, analyses made of the material transmitted, and opinions formulated regarding the acceptability of the received pictures. The early equipment required the preparation of the material for transmission as a film transparency in an area not exceeding $4^{1}/_{4}$ inches by $6^{1}/_{2}$ inches. This relatively small image field combined with the use of 100 scanning lines per inch and the added photographic operations to prepare the material for transmission were considered as limiting the usefulness of this new service. For example, in transmitting many of the forms of printed matter it was necessary to divide the copy into overlapping sections, to transmit each piece separately and to assemble the sections as a composite picture at the receiving point. Obviously this procedure could not be applied advantageously to a photograph or news picture and therefore the maximum information content of such transmissions was limited by the small size of image field and the number of scanning lines employed. Certain types of pictures such as portraits, small groups, and others of a rather limited information content were transmitted satisfactorily with this early equipment, but transmissions of those pictures containing much greater amounts of information frequently were regarded as inadequate.

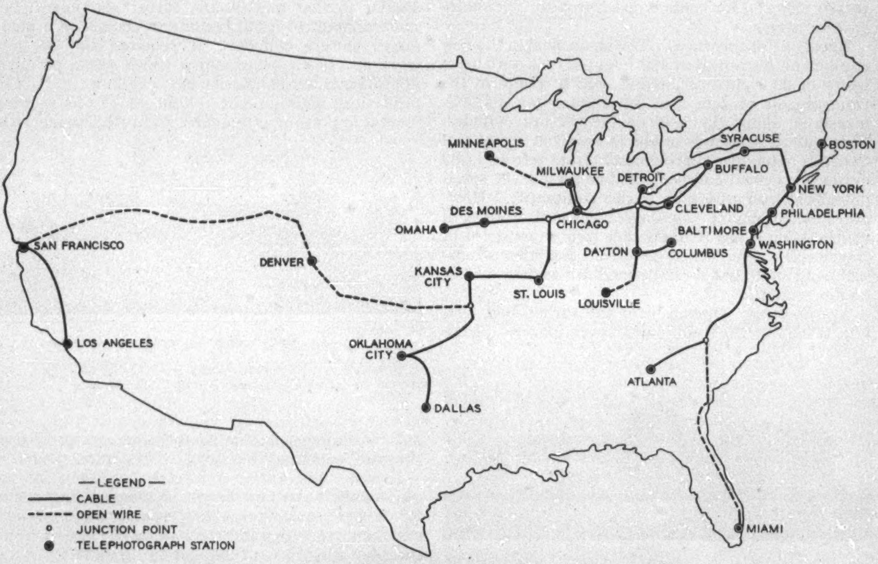


Fig. 1. A leased wire telephotograph network in the United States

In formulating specific requirements for the new telephotograph system consideration also was given to the increasing interest in news pictures and to the trend in this country toward improvement of newspaper halftone reproduction. The former public demand for pictures of the occasional catastrophe or outstanding news event is today apparently being supplemented by an interest in the pictorial reporting of even minor news items. These factors are reacting to elevate the standards for acceptable telephotographs to a plane where newspaper halftone reproduction of original and transmitted pictures may soon be comparable in quality and information content. The requirements met by the new telephotograph system are summarized briefly in the following paragraphs.

Scanning. Pictures are scanned by reflected light at 100 lines per inch. This permits direct transmission from original subject matter in the majority of cases without recourse to special preparation such as photographic copying.

Size of Image Field. A useful image field is provided for scanning and reproducing pictures of various sizes up to and including 11 inches by 17 inches. This area is sufficient to accommodate most sizes of subject matter likely to be encountered in telephotography and is well adapted to transmission of black and white information such as financial statements, advertising layouts, and the like. Furthermore, it provides a practical method of varying the information content of received pictures by using original prints of appropriate sizes. The useful circumference of the picture cylinder employed is 11 inches. In the case of news pictures, which are ordinarily distributed as 8 by 10 inch photographic prints, the remaining one-inch space on the circumference of the cylinder may be utilized for transmitting the caption as part of the picture.

---

[1] For all numbered references see list at end of paper.

The information content of telephotographs is a function of the area of the image field and number of scanning lines employed. This quantity has sometimes been expressed arbitrarily in terms of picture elements, a picture element being considered a unit square having as its dimensions the scanning line pitch. On this basis an 8 by 10 inch picture transmitted with the new Bell System equipment has 800,000 picture elements as compared with a maximum of 280,000 for the early equipment and approximately 660,000 for commercial European telephotograph systems.

Speed of Transmission. The image field in the new equipment is scanned at 100 lines per inch with a velocity of 20 inches per second, which results in the transmission of one inch of picture per minute, measured along the axis of the picture cylinder. This rate of scanning produces essential signal frequencies extending approximately from zero to 1,000 cycles per second and is more than double the speed of transmission used in the earlier equipment. However, by employing the single-side-band method of transmission it has been possible to use this speed of transmission over telephone circuit facilities of normal band width but specially modified as described in a later section.

Synchronism. Operation of the earlier Bell System telephotograph equipment over long telephone circuits indicated the desirability of providing improved means for synchronizing the sending and receiving equipment. Accordingly, developmental work was undertaken, and local frequency sources of the required stability were made available to permit independent speed control without transmitting synchronizing signals. Experimental oscillator units were installed for tests at 3 telephotograph stations about 2 years after the opening of the public telephotograph service in 1925. Experience gained from the use of these oscillators, which were vacuum tube driven tuning forks maintained within close temperature limits, indicated that this method was practicable, although the particular arrangements employed at that time could be advantageously improved.

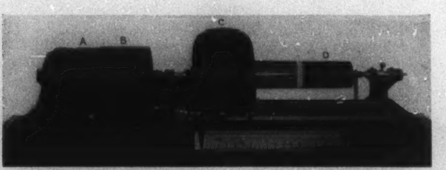


Fig. 2. Telephotograph transmitting machine

A—Motor
B—Clutch
C—Optical system
D—Picture cylinder

A new design of tuning fork controlled oscillator has been provided in the new equipment whose frequency can readily be adjusted and maintained constant to within a few parts in a million. This difference in speed between sending and receiving machines is so slight that skewing of the received picture is not noticeable.

Starting and Phasing. The simultaneous starting of all machines participating in the transmission and reception of a picture is effected by means of a signal sent over the line by the transmitting machine. Phasing of the machines is automatic, since all are started simultaneously from the same angular position by a positive action clutch. This requirement is similar to that met by the earlier equipment, but more difficult to fulfill because of the use of a much larger picture cylinder. It required the development of a new type of clutch which would permit a gradual increase in velocity of the cylinder and yet be positive in action. The fulfillment of this requirement is important as it assures accurate phasing without consuming valuable circuit time, irrespective of the number of machines involved in a transmission.

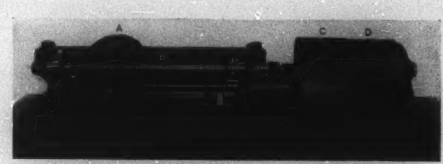


Fig. 3. Telephotograph receiving machine

A—Optical system
B—Cylinder housing
C—Clutch
D—Motor

Design. In addition to meeting the above general requirements the new design includes arrangements for daylight operation, a new type of driving motor, and scanning with a pulsating beam of light whereby the photoelectric current can be amplified by a-c methods.

DESCRIPTION OF THE NEW TELEPHOTOGRAPH EQUIPMENT

The general specifications outlined in the preceding paragraphs are embodied in the new telephotograph equipment now being manufactured. Telephotograph equipment of this type for a station arranged to send and receive pictures consists of a sending machine and a receiving machine mounted on separate tables (see figures 2 and 3), 2 bays of relay-rack-mounted apparatus, and a cabinet of power supply equipment. A third bay comprising loop terminating arrangements, telephone, and loud speaker equipment may be furnished by the telephone company if ordered by the customer. This telephotograph equipment connected by suitable circuits will transmit pictures and other forms of graphic information from point to point or from one to a number of points simultaneously.

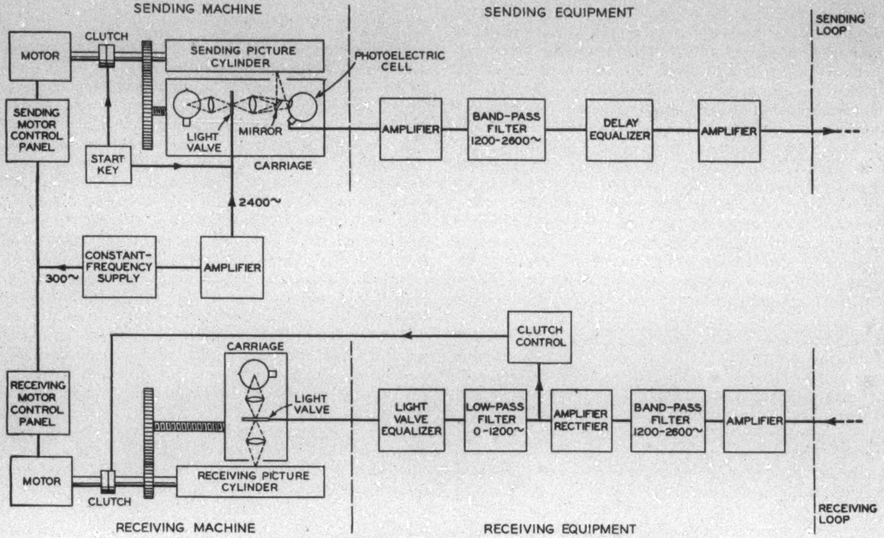

SENDING MACHINE
SENDING EQUIPMENT
SENDING LOOP
MOTOR
CLUTCH
SENDING PICTURE CYLINDER
PHOTOELECTRIC CELL
SENDING MOTOR CONTROL PANEL
LIGHT VALVE
MIRROR
AMPLIFIER
BAND-PASS FILTER 1200-2600~
DELAY EQUALIZER
AMPLIFIER
START KEY
CARRIAGE
2400~
CONSTANT-FREQUENCY SUPPLY
300~
AMPLIFIER
CLUTCH CONTROL
CARRIAGE
RECEIVING MOTOR CONTROL PANEL
LIGHT VALVE
LIGHT VALVE EQUALIZER
LOW-PASS FILTER 0-1200~
AMPLIFIER RECTIFIER
BAND-PASS FILTER 1200-2600~
AMPLIFIER
MOTOR
RECEIVING PICTURE CYLINDER
CLUTCH
RECEIVING MACHINE
RECEIVING EQUIPMENT
RECEIVING LOOP

Fig. 4. Schematic diagram of sending and receiving equipment for one station

Figure 4 is a schematic diagram illustrating the functional relationships of the various units of this equipment. Certain features of these units that may be of special interest have been selected for description in the following.

Motor and Associated Speed Control Circuit. Although the driving motor for the telephotograph machine is essentially of the d-c shunt type, it functions in combination with its associated speed control equipment as a synchronous unit and upon starting locks automatically in synchronism with the frequency generated by the local carrier and motor control oscillator. This is accomplished in a manner similar to that previously used in television equipment demonstrated by the Bell System.[2,3] An inductor type generator built into the frame of the motor delivers an a-c output of 300 cycles per second at the normal speed of the motor, 100 rpm. The output of the generator is impressed upon the plates of 2 vacuum tubes the grids of which are energized by the 300 cycle output of the carrier and motor control oscillator as shown in figure 5. These tubes act as a phase detector and vary the input voltage across an amplifier which supplies the total armature current of the motor. Armature rather than field control is employed to obtain faster and more complete regulation. The capacitor across the terminals of the generator armature, tuning the circuit to a frequency slightly in excess of 300 cycles per second, and the coupling impedance between phase detector and amplifier acting as a low pass filter, assist in preventing hunting of the motor.

Clutch. Connection between driving motor and picture machine is made through a positive action clutch electrically operated. This clutch gradually applies the driving torque to the picture machine during the starting interval. It operates on the principle of storing energy in a coiled spring during the first part of the starting interval while the velocity of the machine is increasing and then allowing this energy to be released gradually by an escapement mechanism while the parts of the clutch are assuming their normal operating position. The time interval required for complete operation of the clutch corresponds to 3 or 4 revolutions of the picture cylinder but variations in the length of this interval do not affect the accuracy of phasing, inasmuch as the latter is determined by the time of operation of the clutch trip magnet and each receiving machine may be readily adjusted to compensate for this variation.

Circuit arrangements associated with the clutch of the receiving machine permit its operation from a starting signal received over the line from the transmitting machine.

Sending Optical System. The optical system of the sending machine is arranged to direct a scanning light beam upon the surface of the picture which is mounted on a cylinder. This scanning beam, attenuated by reflection from the various shades of the picture, is directed to a photoelectric cell. The illumination is obtained from a small incandescent lamp and is interrupted in passing through the aperture of a double ribbon light valve. This double ribbon light valve, which is a modification of a type previously described,[4] is actuated by the picture carrier frequency, 2,400 cycles per second, and its interruption of the scanning light beam permits the use of a-c methods of amplification of the photoelectric currents. Aside from its general simplicity and freedom from the usual difficulties experienced with rotating light choppers, this type of interrupter readily effects a sinusoidal variation in illumination.

It is obvious that, since the illumination incident upon the picture is pulsating at the carrier frequency, the currents present in the output of the photoelectric cell will consist of the picture signal currents and the carrier frequency modulated by these currents, the picture itself acting as a simple direct product modulator.

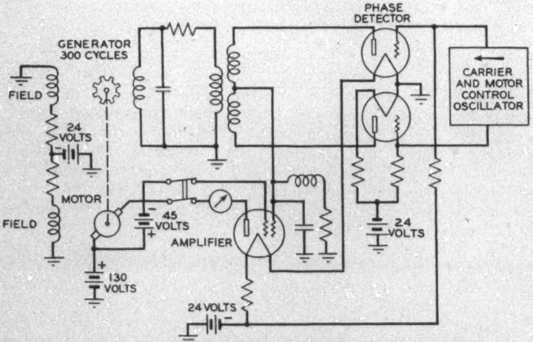


Fig. 5. Telephotograph machine motor control circuit

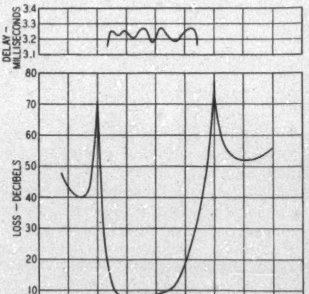


Fig. 6. Over-all characteristics of filters and delay equalizer

Filters and Delay Equalizer. The application of single-side-band transmission methods to the present telephotograph equipment has resulted in the design of electrical filters of rather unusual phase shift and attenuation-frequency characteristics. It has previously been pointed out in connection with a discussion of telegraph transmission theory[5] that 3 conditions should be fulfilled for single-side-band transmission:

1. The system should have a linear phase shift-frequency characteristic.

2. The sluggish in-phase component of the signal resulting from a displacement of the carrier from the middle of the transmitted band should be eliminated.

3. The received quadrature component resulting from the loss of the component of the side band suppressed, equal in magnitude but opposite in sign, should also be eliminated.

The first 2 conditions are met by the careful design of a delay equalizer network and a special filter giving a suitably shaped admittance characteristic for the system. This characteristic exhibits a type of symmetry about the carrier frequency which would result in a superposition of the regions adjacent to the carrier if rotated about this point. Consequently the attenuation of the filters and associated delay equalizer should be 6 decibels greater at the carrier frequency than at the middle of the band of the transmitted frequencies, in addition to meeting the requirement of a linear phase shift-frequency characteristic. Over-all attenuation and phase shift-frequency characteristics of the filters and equalizer of the sending and receiving equipment of the present design are shown in figure 6.

In regard to the third condition for single-side-band transmission, experiments have shown that the effect in received pictures of the quadrature component is not of practical importance in the present equipment. The quadrature component is determined essentially by the slope of the signal envelope which is in turn restricted by the equivalent transfer admittance characteristic[6] of the scanning aperture, and by the slope of the filter characteristic to meet condition 2.

Receiving Optical System. The receiving optical system of the new telephotograph equipment is similar in its general aspects to that employed in the earlier Bell System equipment. Illumination from an incandescent lamp is directed to the receiving photographic emulsion through the aperture of a single ribbon light valve. The latter, however, is operated by the rectified picture currents instead of by the modulated picture carrier current as used in the earlier equipment. This change results in very simple yet efficient optical arrangements for receiving a variable density constant line width picture with no apparent structure. The aperture of the light valve, which is uniformly illuminated by the incandescent lamp, is adjusted so that the width of its image on the receiving emulsion is 0.01 inch. The height of the aperture, which determines the exposure, is regulated by the instantaneous position of the light valve ribbon and this is proportional to the received picture currents. A uniformly illuminated field is obtained at the light valve aperture with a minimum loss of light by using a sphero-cylindrical condenser lens which focuses the diameter of the helical filament of the lamp without imaging individual turns of the helix at the plane of the aperture. Imaging of the lamp filament with the usual type of spherical condenser lens would result in nonuniformity of illumination not only because interstices between individual turns of the helix have an intrinsic brilliancy much greater than the outer surface of the filament but also because of the angular variation of the masking effect of the turns of the helix upon the illumination emerging from the interstices. The ribbon of the light valve is tuned mechanically to resonance at 1,200 cycles per second, and is shunted by an equalizer[7] consisting of inductance, capacitance, and resistance in series which is tuned to the resonant frequency of the ribbon, thereby producing a flat response-frequency characteristic over the useful range of signal frequencies.

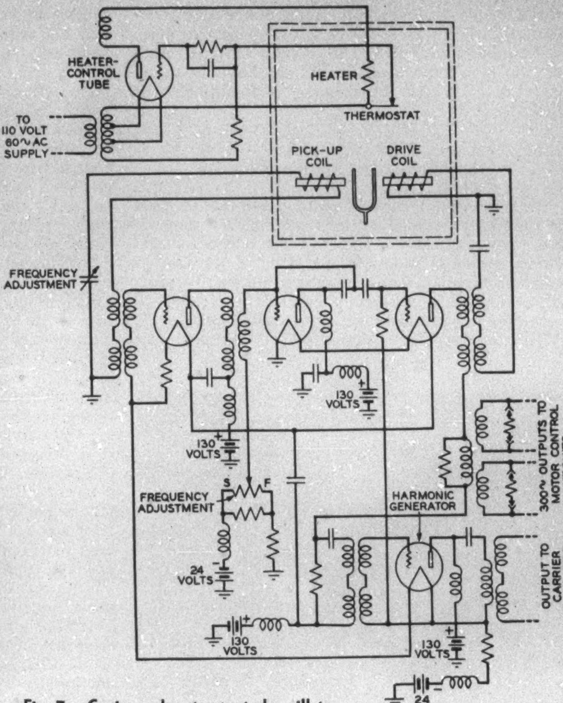


Fig. 7. Carrier and motor control oscillator

Carrier and Motor Control Oscillator. This portion of the equipment furnishes the carrier frequency of 2,400 cycles per second and the motor control frequency of 300 cycles per second accurate to within a few parts in a million. The arrangements used consist of a 300 cycle tuning fork within a temperature regulated container, a vacuum tube amplifier circuit designed to provide controlled regenerative operation of the fork, and a vacuum tube harmonic generator for supplying the carrier frequency.

Although this general method for obtaining a constant frequency is old and has been described previously,[8,9,10] in view of its importance in the operation of the present telephotograph equipment it may be of interest to indicate briefly the specific arrangements employed.

The tuning fork is made of a heat treated nickel chromium steel alloy to obtain a small frequency-temperature coefficient and is mounted in a thermostatically controlled metal cylinder wound with a heating coil over which are wrapped alternate layers of copper and felt to provide attenuation of heat transfer.[11] The pickup and drive coils associated with the fork are connected to the vacuum tube amplifier circuit as shown in figure 7. The frequency of a fork is affected by a number of factors including temperature, amplitude of vibration, and aging of the material. Since it is impracticable to maintain constant all of the factors involved, it is necessary to provide means for occasional adjustment to meet the requirements for constancy desired in picture transmission. In the present equipment the temperature of the fork is maintained within ±0.1 degree of its nominal value of 50 degrees centigrade; 2 adjustments are provided for changing the amplitude, one of which varies the grid potential of a vacuum tube which acts to limit the current supplied the driving coil, and the other, a variable capacitor in the circuit containing the pickup coil varies the phase relation between the currents in the drive and pickup coils. Three outputs are provided from the oscillator, 2 for the sending and receiving motor control circuits and the third for the carrier frequency supplied the sending light valve. All of these outputs terminate in high impedance circuits and have no appreciable reaction upon the constancy of operation of the fork.

LINE FACILITIES USED WITH THE NEW TELEPHOTOGRAPH EQUIPMENT

Requirements for the communication channel used in the transmission of pictures are obviously dependent upon the characteristics of the telephotograph equipment employed and the amount of degradation resulting from transmission which can be tolerated. In general, telephotograph equipment capable of recording the transmitted signals with a degree of fidelity of the order required for good pictures may also record certain extraneous disturbances in the transmission channel which will appear as blemishes on the received picture. The more important of these disturbances are abrupt variations in line net loss, delay distortion, certain types of noise, echoes, and crosstalk. With the exception of delay distortion which is more pronounced for the new equipment because of its higher speed of transmission, the requirements relating to the other disturbances are comparable to those applying to the earlier Bell System equipment. Experience over a period of years with the earlier equipment indicated that selected telephone circuits, specially conditioned to adapt them to picture transmission and established as a regular network, could be relied upon to give consistently good results. This general procedure has been followed in establishing wire networks for use with the new telephotograph equipment and typical examples of pictures received over such circuits are shown in figures 8 and 9.

Fig. 8. Telephotograph received at New York from Los Angeles. Reproduced by courtesy of the Associated Press

The circuit facilities employed with the new telephotograph system are 4-wire *H*-44-25 side circuits in cable[12] where available and elsewhere 2-wire open-wire[13] side and physical circuits.* These facilities are provided with delay equalizer networks for the frequency range from 1,200 to 2,600 cycles per second and precautions are taken to minimize various transmission disturbances. Means are provided, controlled by the sending telephotograph equipment, to prevent operation of the transmission regulating network relays on cable circuits during the transmission of a picture, and to obtain one-way transmission over 2 wire circuits. A wire network of nearly 8,000 miles established as outlined above and connecting 26 stations of the new telephotograph equipment has been in operation for more than a year, giving reliable and technically satisfactory service.

Transmission Requirements. The effects of extraneous line disturbances may or may not be particularly objectionable in a specific case, depending upon their magnitude and form and also on the nature and use of the received picture. Furthermore, the predominance of the recorded disturbance may also be affected by normal variations in the adjustments of the telephotograph equipment. It is not practicable, therefore, to establish precise limits for the transmission requirements. The following values are mentioned as illustrative of the order of magnitude for some of the more important requirements applying to circuits used with the new telephotograph equipment, and which experience has shown will give generally satisfactory results.

(*a*) *Line Net Loss.* Abrupt variations in line net loss of 0.2 decibel or greater usually will produce a noticeable change in shade of the received picture. However, a gradual variation in net loss occurring over a period of minutes is less objectionable and in many instances a change of as much as 2 or 3 decibels during a transmission can be tolerated.

(*b*) *Noise.* Noise of a single-frequency type is likely to be recorded in the received picture as an objectionable *moiré* pattern if the difference between the maximum signal and interference energy is less than 50 decibels. However, if the interference energy is distributed over a relatively wide frequency band an energy difference of about 35 decibels usually can be tolerated.

(*c*) *Delay Distortion.* Delay distortion introduced by the circuit, if of sufficient magnitude, may pro-

---

* A side circuit is a physical circuit that is used for one of the paths of a phantom circuit; the notation *H*-44-25 indicates a loading coil spacing of 6,000 feet, inductance of physical or side circuit loading coils 44 millihenries, and inductance of phantom circuit loading coils 25 millihenries.

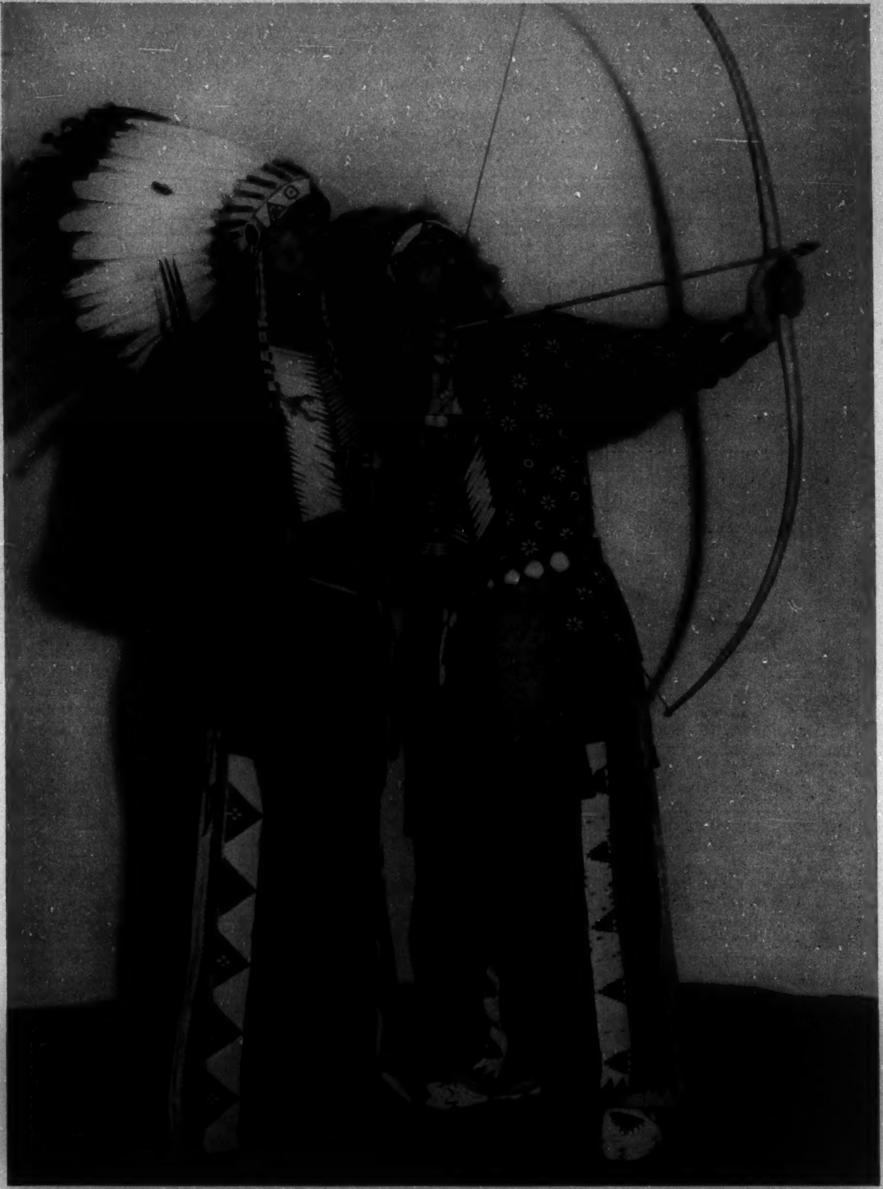


Fig. 9. A telephotograph (original size 10½ by 14¼ inches) that reveals the fineness of detail that may be transmitted by equipment now in service. Reproduced by courtesy of the Associated Press

duce multiple outlines along the edges of objects or lines in the received picture and result in a loss or general masking of picture detail. In order that this effect may be inappreciable in pictures received with the new telephotograph equipment it is desirable that the maximum deviation in envelope delay throughout the useful frequency band (1,200 to 2,600 cycles per second) be less than ±300 microseconds.

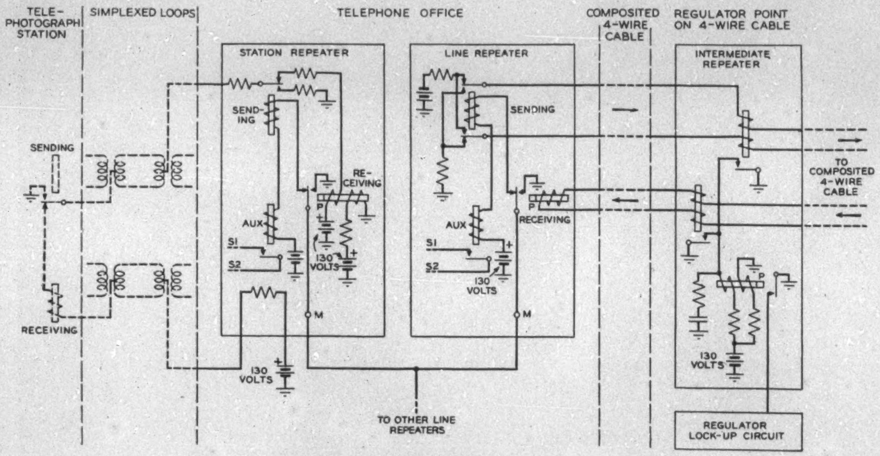

TELE-PHOTOGRAPH STATION
SIMPLEXED LOOPS
TELEPHONE OFFICE
COMPOSITED 4-WIRE CABLE
REGULATOR POINT ON 4-WIRE CABLE
STATION REPEATER
LINE REPEATER
INTERMEDIATE REPEATER
SENDING
SEND-ING
SENDING
RE-CEIVING
RECEIVING
RECEIVING
AUX
AUX
S1
S2
S1
S2
P
P
P
130 VOLTS
130 VOLTS
130 VOLTS
130 VOLTS
130 VOLTS
M
M
TO OTHER LINE REPEATERS
TO COMPOSITED 4-WIRE CABLE
REGULATOR LOCK-UP CIRCUIT

Fig. 10. D-c control circuit repeaters

D-C Control Circuit. Sudden small variations in line net loss are normal on toll cable circuits in the United States as the result of the stepping of the regulating network relays, which, under control of a pilot wire regulator, compensate for the effect of temperature changes on the attenuation of the circuit. Since these sudden variations in net loss produce noticeable changes in shade of the received picture, means similar to those employed with the earlier Bell System telephotograph equipment have been made available to prevent these relays from operating while a picture is being transmitted. Simple types of control units actuated by signals transmitted over a control circuit are connected to each regulating repeater associated with the picture circuit. This control circuit consists of 2 one-way d-c channels obtained by compositing the telephotograph circuit and extended to each telephotograph station over simplexed loop arrangements. The control circuit is also arranged to perform other functions such as effecting one-way transmission of the 2 wire circuits during a picture transmission. The operation of the control circuit normally is performed automatically at the sending telephotograph station.

Inasmuch as the transmission requirements for this control circuit are very lenient compared with those for telegraphy, it has been possible to employ simple types of d-c repeaters as illustrated in figure 10. A signal from the subscriber's sending equipment operates the receiving relay of the station repeater, which in turn places a ground on the *M* lead and thus transmits the signal to all line repeaters which may be associated with this junction. Only one direction of operation at a time is possible so that when a sending telephotograph station takes control at the beginning of a picture transmission the control circuit is operated and remains in this condition until released automatically at the end of the transmission. A slow release circuit is provided in the d-c repeater used at regulating network points on the cable circuits and also in another type of repeater, not shown but used on open-wire circuits to obviate false operation of the

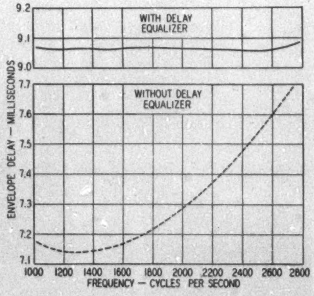


Fig. 11. Delay characteristic of 135 miles of H-44 repeatered and composited side circuit before and after equalization

repeaters as the result of interruptions of less than 2 seconds duration.

Delay Equalization. Delay equalization[14] of telephotograph circuits is not new, but was applied in 1925–26 to certain medium-heavy loaded toll cable circuits between New York and Boston which were used in the early Bell System telephotograph service. (This application was discussed in reference 14 relative to delay distortion, and examples of transmitted printed matter were reproduced.) However, because of the increased speed of transmission of the new telephotograph equipment and the demand for longer circuits for picture transmission it has been necessary to make further application of delay equalization to some of the more common types of circuits used for this purpose.

Delay distortion in *H*-44-25 cable circuits, which is largely the result of the loading, has been compensated by delay networks consisting of a basic unit correcting for 150 miles of composited 19-gauge side circuit, adjustable in 10-mile steps, and a "mop-up" unit of 4 sections for more complete compensation. A balanced lattice type of structure was used in the design of these equalizers. Figure 11 illustrates the application of equalizer units to cable circuits and shows the delay characteristics before and after equalization. Similar types of delay equalizers have been applied to open wire circuits, in which case it is the equipment located at the repeater stations rather than the line itself which is responsible for delay distortion. The delay equalizers are normally located at terminal and bridging points on the telephotograph network and at some intermediate points such as junctions of open-wire and cable circuits.

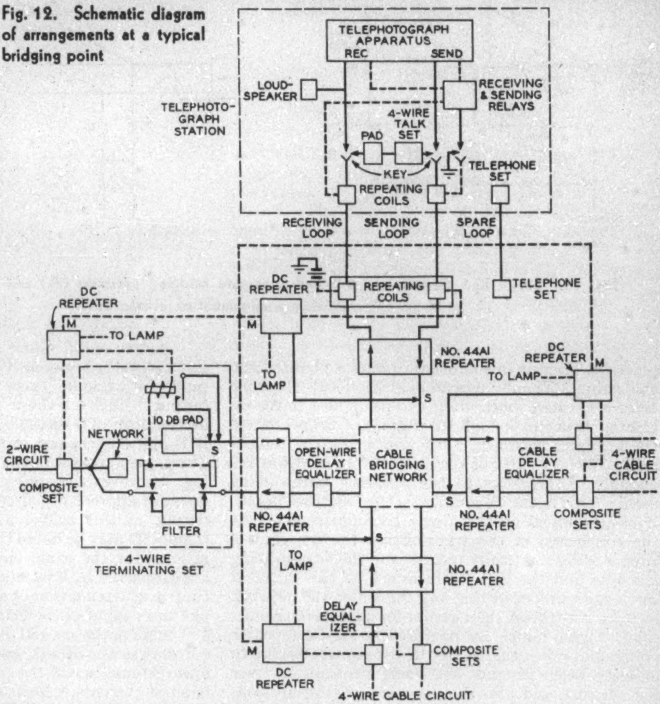


Fig. 12. Schematic diagram of arrangements at a typical bridging point
TELEPHOTOGRAPH APPARATUS
REC
SEND
LOUD-SPEAKER
TELEPHOTO-GRAPH STATION
RECEIVING & SENDING RELAYS
4-WIRE TALK SET
PAD
KEY
TELEPHONE SET
REPEATING COILS
RECEIVING LOOP
SENDING LOOP
SPARE LOOP
DC REPEATER
REPEATING COILS
TELEPHONE SET
DC REPEATER
M
TO LAMP
M
TO LAMP
NO. 44A1 REPEATER
DC REPEATER
M
TO LAMP
S
10 DB PAD
NETWORK
S
2-WIRE CIRCUIT
COMPOSITE SET
OPEN-WIRE DELAY EQUALIZER
CABLE BRIDGING NETWORK
CABLE DELAY EQUALIZER
4-WIRE CABLE CIRCUIT
S
FILTER
NO. 44A1 REPEATER
NO. 44A1 REPEATER
COMPOSITE SETS
4-WIRE TERMINATING SET
S
TO LAMP
NO. 44A1 REPEATER
DELAY EQUAL-IZER
M
COMPOSITE SETS
DC REPEATER
4-WIRE CABLE CIRCUIT

TELEPHOTOGRAPH NETWORKS

One of the obvious advantages of network operation of telephotograph stations is that it offers a means for rapid and simultaneous distribution of facsimile information and pictures to a large number of receiving points. This method of operation appears to be particularly advantageous for use by the large news-picture gathering and distributing agencies giving a nation-wide service. Such network operation of a number of telephotograph stations presents additional requirements, not mentioned in the preceding paragraphs, which may be of general interest.

Requirements encountered in connecting a large number of sending and receiving stations were that any sending station should be able to transmit a picture simultaneously to all receiving stations, and that any one station could be selected as the transmitting point, establishing a new direction of transmission with a minimum of lost time. The situation has been met by permanently bridging each telephotograph station, consisting of separate sending and receiving equipment, to the wire network on a 4 wire basis using separate sending and receiving station loops and performing automatically such switching operations as may be involved in altering the direction of transmission.

Typical arrangements which have been used at a bridging point on a telephotograph network are illustrated in figure 12. Suppose, for example, that the telephotograph station at this point wishes to transmit a picture to the network. Operation of a key associated with the subscriber's telephotograph transmitting equipment sends out a d-c signal over the simplexed loop to the control circuit station repeater at the local telephone office. Since this repeater is multipled with the d-c repeaters associated with each of the telephotograph circuits connected at this point, the signal is transmitted over the entire network and the switching operations performed to place the circuits in condition to send a picture from this point. The d-c repeaters at the local telephone office also cause short circuits to be applied to the incoming transmission paths which are connected to the bridging networks, thus preventing the temporarily inactive parts of the circuit from contributing possible disturbances to the outgoing paths being used. This figure also indicates the switching operations performed on the 4 wire terminating set. At the conclusion of the transmission the d-c control circuit is automatically released by the transmitting machine and the circuits returned to the initial 2 way condition permitting any station on the network to seize control of the circuits for picture transmission. Signal lamps are provided at all d-c repeater points and are actuated by the d-c control circuit to indicate when pictures are being transmitted over the network and also the direction of transmission.

The problems involved at junction points in connecting a number of circuits, particularly of the 4 wire type, have been simplified through the use of a new form of bridging network. Although this situation could be met by employing unilateral devices such as vacuum tube amplifiers, it was found that comparable results could be obtained simply and at less expense with interconnected resistance type pads. Two designs of such networks, essentially alike except for the values of attenuation provided, are in use, one for cable and the other for open-wire circuits. These bridges are used not only at junctions of circuits forming the network but also at all points at which telephotograph stations are connected.

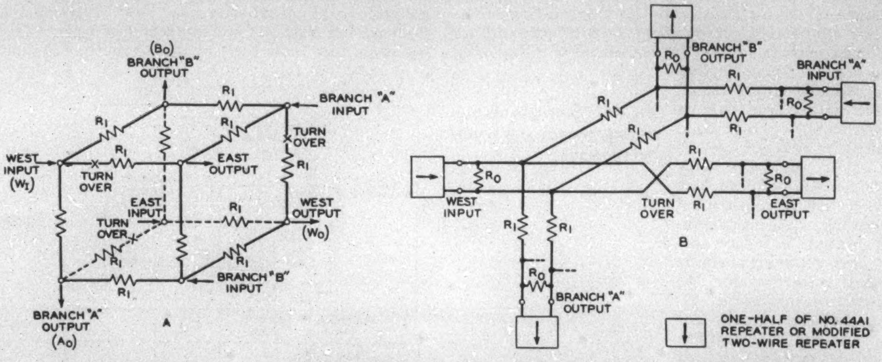


Fig. 13. Single line diagram of cable and open-wire bridging networks (A) and portion of cable bridge showing arrangement of resistances (B)

A single line schematic of the type of bridging network employed is shown in figure 13*A*, and a more complete representation of a portion of the network used on cable circuits is shown in figure 13*B*. Current entering the bridge, for example at W_I, traverses 3 direct paths of equal attenuation and leaves at B_O, A_O, and E_O. There are, of course, numerous indirect paths between W_I and each of the bridge outputs; for example, there are 2 parallel paths to each output. Each of these 2 paths has 3 times the attenuation of a direct path and the current through it is 180 degrees out of phase with that through a direct path because of the reversals shown in the wiring. However, the aggregate of all of the indirect paths does not appreciably alter the loss between input and output of this bridge as calculated by neglecting them. It may be noted that the 2 directions of transmission for the same circuit, between W_I and W_O, are connected by 6 parallel paths each of which has 3 times the attenuation of a direct path between an input and output of the bridge. The currents through 3 of these paths are 180 degrees out of phase with the currents in the others, and hence would result in infinite attenuation of the echo were it not for small unbalance currents. Measured crosstalk losses for the echo paths in excess of 70 decibels have been obtained for these bridging networks manufactured with ordinary tolerances.

Certain auxiliary features may also be incorporated in telephotograph networks to assist in their operation and perform other related functions. For example, telephotograph methods are not efficient in their present form for the rapid exchange of operating instructions so that telephone facilities may be associated with a telephotograph network for use by the customer in co-ordinating the operation of this system. Arrangements may be used whereby such voice communication may be carried on over the telephotograph circuit between picture transmissions, and loud-speakers may be bridged on the circuit for monitoring purposes.

References

1. The Transmission of Pictures Over Telephone Lines, H. E. Ives, J. W. Horton, R. D. Parker, and A. B. Clark. *Bell System Technical Journal*, v. 4, April 1925, p. 187–214.

2. Synchronization of Television, H. M. Stoller and E. R. Morton. *Bell System Technical Journal*, v. 6, Oct. 1927, p. 604–15.

3. Synchronization System for Two-Way Television, H. M. Stoller. *Bell System Technical Journal*, v. 9, July 1930, p. 470–6, and discussion, p. 477.

4. A Permanent Magnet Light Valve, G. E. Perreault. *Bell Laboratories Record*, v. 10, Aug. 1932, p. 412–16.

5. Certain Topics in Telegraph Transmission Theory, H. N. Nyquist. A.I.E.E. Transactions, v. 47, April 1928, p. 617–44.

6. A Theory of Scanning and Its Relation to the Characteristics of the Transmitted Signal in Telephotography and Television, Pierre Mertz and Frank Gray. *Bell System Technical Journal*, v. 13, July 1934, p. 464–515.

7. An Oscillograph for Ten Thousand Cycles, A. M. Curtis. *Bell System Technical Journal*, v. 12, Jan. 1933, p. 76–90.

8. The Use of the Triode Valve in Maintaining the Vibration of a Tuning Fork, W. H. Eccles. Physical Society (London) *Proceedings*, v. 31, 1918–19, p. 269.

9. Frequency Measurement in Electrical Communication, J. W. Horton, N. H. Ricker, and W. A. Marrison. A.I.E.E. Transactions, v. 42, June 1923, p. 730–41.

10. Precision Determination of Frequency, J. W. Horton and W. A. Marrison. I.R.E. *Proceedings*, v. 16, Feb. 1928, p. 137–54.

11. Thermostat Design for Frequency Standards, W. A. Marrison. I.R.E. *Proceedings*, v. 16, July 1928, p. 976–80.

12. Long Distance Telephone Circuits in Cable, A. B. Clark and H. S. Osborne. *Bell System Technical Journal*, v. 11, Oct. 1932, p. 520–45.

13. The Transmission Characteristics of Open Wire Telephone Lines, E. I. Green. *Bell System Technical Journal*, v. 9, Oct. 1930, p. 730–59.

14. Phase Distortion and Phase Distortion Correction, Sallie P. Mead. *Bell System Technical Journal*, v. 7, April 1928, p. 195–224.

An Analysis of the Shaded Pole Motor

The shaded pole motor is considered the most popular type of single phase induction motor in the small fractional horsepower range, and is widely used for driving fans. The general forms of construction are outlined in this paper, in which the equations for this type of motor are derived and the performance characteristics are discussed.

By
P. H. TRICKEY
ASSOCIATE A.I.E.E.

Diehl Manufacturing Co.,
Elizabethport, N. J.

INHERENTLY the shaded pole motor is of fractional horsepower rating, and as the fractional horsepower motor is a result of ventilating fan development, so the shaded pole motor is an outcome of the fan industry. It was not very long after Tesla developed the 2 phase induction motor that engineers discovered that a motor would start and run when both phases were connected to a single phase line, provided that the resistances and reactances of the windings were suitably proportioned. The carrying on of this development has resulted in the well-known split-phase motor, which runs single phase on one winding and has a high resistance winding connected in parallel during the starting period.

Inasmuch as the building of very small motors which will operate satisfactorily on a single phase supply is sometimes difficult, it is considered desirable many times to leave the starting winding connected even during the running period. Because an outside resistance is ordinarily used in series with the starting winding, this type is often called the resistance split-phase motor. As a general rule, these motors are preferable to normal split-phase motors only in sizes below $^1/_{100}$ horsepower, but they have often been used for ratings as high as $^1/_{20}$ horsepower to avoid the cost of a starting switch or cutout.

From 1889 until about 1919, these 2 types of split-phase induction motors were used very extensively on fans and whatever other applications there were for fractional-horsepower single-phase motors. Along with these there were and still are a great many commutator motors of the series type, their main advantage being their ability to operate on either a-c or d-c lines.

About 1894 it was discovered that a squirrel cage motor with a salient-pole single-phase field would run if a portion of the pole were short-circuited with a winding or coil. Since then the saving in the cost of this winding, compared with the distributed field winding of the split-phase type, has gradually given this "shaded pole" motor tremendous popularity, until today it far overshadows all other single phase types for ratings below $^1/_{20}$ horsepower.

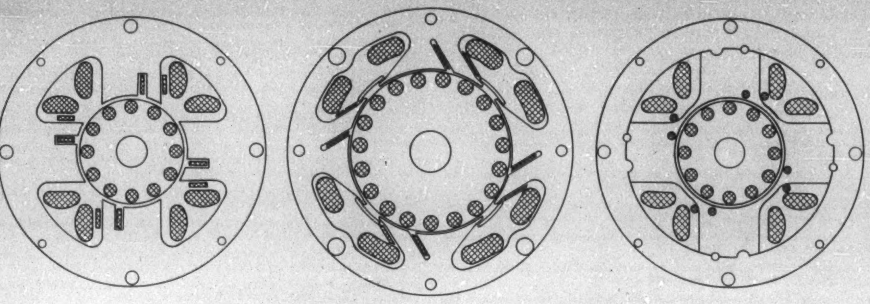
Principle of Operation of Shaded Pole Motor

If there were no shading coil on the salient pole, the flux in that pole and in the air gap under it would

---

A paper recommended for publication by the A.I.E.E. committee on electrical machinery. Manuscript submitted January 3, 1936; released for publication February 17, 1936.

The author wishes to acknowledge the assistance of E. W. Denman, R. H. Jordan, and J. H. Godfrey, all of the Westinghouse Electric and Manufacturing Company, without whose experience as a check the preparation of this paper would have been impossible.



Figs. 1–3. Examples of typical shaded pole motor construction

simply alternate from positive to negative and no rotational effect would be produced. However, the shading coil causes the flux in that portion of the pole to lag a small fraction of the time cycle behind the flux in the main part of the pole. This causes the points of maximum flux to progress around the motor, and results in a rather poor rotating field which draws the rotor around with it, as in any induction machine. The rotation is, of course, from the main pole toward the shaded pole.

TYPES OF CONSTRUCTION

Motors using the shaded pole principle have been developed in many forms, and in greatly varying proportions, although the rotor is almost invariably a simple squirrel cage rotor. Figure 1 shows a most typical construction. The stator core is composed of single-piece identical laminations held together by rivets near the periphery. The main winding consists of coils wound on a form and then slid on over the pole. The shading winding is simply 4 coils of one turn each of bare copper strap, each coil short-circuited on itself. It can be shown that it makes no difference in any short-circuited winding whether all the poles are short-circuited in series or each one short-circuited alone. Therefore the simple coil is used.

Figure 2 shows a similar construction except that iron wedges bridge the pole tips. As a general rule the increased leakage flux of the shaded pole results in a motor of more desirable characteristics.

Since the magnetic wedges are so often desirable advantage is sometimes taken to construct the wedge as part of the pole as shown in figure 3. The stator core is made in 2 parts, an outside ring and an inner spider, each built up of laminations and riveted. The main coils are very easily slipped over the spider, then the ring pressed on over it. Its simplicity of winding is so great that for small sizes this type is very popular. It has the disadvantages of a spongy core, of having to complete the shading coils after putting them on the core, and of a slight air gap at the joint between the 2 parts of the core.

The shaded pole motor is very adaptable to the consequent pole type of winding, in which only part of the coils are wound. The shading coils also may be consequent. Occasionally the shading coils are distributed in 2 or more slots per pole. Sometimes the shading coil is made of a piece of copper wire or strap, wrapped around the shaded pole, and the ends soldered together, and at other times as shown in figures 1 and 2, the shaded pole is so shaped that the shading coil may be slipped into place after forming. In these cases the shading coil is often made by cutting from a copper tube whose rectangular section is exactly the shape of the shaded pole area it is to enclose.

Figure 4 shows to what extent the shaping of the field structure may be varied. The primary laminations in this case have only one joint, but alternate punchings are reversed, and stacked in the coil in the same manner as in small transformers.

CIRCUIT ANALYSIS

Figure 5 shows the diagram of a typical shaded pole motor. There are 4 circuits to be considered in analyzing this motor: primary, shading coil, and 2 rotor phases. In writing the current and voltage equations of these 4 circuits, it becomes necessary first to define the several parts of the motor flux. Letting Φ be the total primary pole flux (this divides into 2 paths in the yoke)

$$\Phi = \Phi_1' + \Phi_m' + \Phi_a'$$

where

Φ_1' = primary leakage flux
Φ_m' = total main pole flux
Φ_a' = total shaded pole flux

Each of these last 2 fluxes may be divided into 4 components:

$$\Phi_m' = \Phi_{mm} + \Phi_{hm} + \Phi_{skm} + \Phi_{bm}$$
$$\Phi_a' = \Phi_{ma} + \Phi_{ha} + \Phi_{ska} + \Phi_{ba} + \Phi_a$$

where

Φ_{mm} = fundamental sine wave component of the main pole flux crossing the air gap
Φ_{hm} = sum of all the harmonics of the main pole flux
Φ_{skm} = that part of the main pole flux which is lost to the rotor because of skewing

Φ_{bm} = magnetic bridge flux entering the main pole

The same relations hold for the shaded pole fluxes, and in addition

Φ_a = shaded coil leakage flux
Φ_2 = rotor leakage flux

Writing the equation for each circuit consists simply of adding all the voltages, induced or consumed, in the circuit.

Primary

$$I_1(r_1 + jx_1') + j(I_1 - I_{2m})X_{mm} + jI_1X_{bm} + jI_1X_{skm} + jI_1X_{hm} + j(I_1 - I_a)(X_{ska} + X_{ha} + X_{ba}) + j(I_1 - I_a - I_{2a})X_{ma} = E$$

Shaded Pole

$$I_a(r_a + jx_a) - j(I_1 - I_a)(X_{ska} + X_{ha} + X_{ba}) - j(I_1 - I_a - I_{2a})X_{ma} = 0$$

Rotor Main Phase

$$I_{2m}(r_{2m} + jx_{2m}) - j(I_1 - I_{2m})X_{mm} - S(I_1 - I_a - I_{2a})X_{ma} + SI_{2a}x_{2a} = 0$$

Rotor Shaded Pole Phase

$$I_{2a}(r_{2a} + jx_{2a}) - j(I_1 - I_a - I_{2a})X_{ma} + S(I_1 - I_{2m})X_{mm} - SI_{2m}x_{2m} = 0$$

If

$x_1 = x_1' + X_{hm} + X_{skm} + X_{bm}$
$X_{a1} = X_{ha} + X_{ska} + X_{ba}$
$X_{o2} = X_{mm} + x_{2m}$
$X_{o3} = X_{ma} + x_{2a}$

there are obtained 4 equations with the 4 currents as unknowns.

$$I_1[r_1 + j(x_1 + X_{mm} + X_{ma} + X_{a1})] - I_a j(X_{a1} + X_{ma}) - I_{2m}jX_{mm} - I_{2a}jX_{ma} = E$$
$$- I_1[j(X_{1a} + X_{ma})] + I_a[r_a + j(x_a + X_{a1} + X_{ma})] + 0 + I_{2a}jX_{ma} = 0$$
$$- I_1[jX_{mm} + SX_{ma}] + I_aSX_{ma} + I_{2m}(r_2 + jX_{o2}) + I_{2a}SX_{o3} = 0$$
$$- I_1[jX_{ma} - SX_{mm}] + I_ajX_{ma} - I_{2m}SX_{o2} + I_{2a}(r_2 + jX_{o3}) = 0$$

The solution of these equations is quite long and complicated, but becomes reasonably usable if $S = 0$, which is the case for standstill conditions.

$$I_1 = \frac{E}{(r_1 + r_2K_{rm} + r_2K_{ra}) + j(X + X_4) - F_1(r_2K_{ra} + jX_4)}$$

$$I_a = I_1F_1 \qquad I_{2m} = I_1F_2 \qquad I_{2a} = (I_1 - I_a)F_3$$

where

$$F_1 = \frac{r_2K_{ra} + jX_4}{(r_a + r_2K_{ra}) + j(X_a + X_4)}$$

$$F_2 = \frac{K_{rm}}{X_{mm}}(X_{o2} + jr_2) \qquad F_3 = \frac{K_{ra}}{X_{ma}}(X_{o3} + jr_2)$$

$$X = x_1 + X_{mm} - K_{rm}X_{o2} \qquad X_4 = X_{a1} + X_{ma} - K_{ra}X_{o3}$$

$$K_{rm} = \frac{(X_{mm}/X_{o2})^2}{1 + (r_2/X_{o2})^2} \qquad K_{ra} = \frac{(X_m/X_{o3})^2}{1 + (r_2/X_{o3})^2}$$

The torque may be found from the equation given in a discussion by C. R. Boothby (A.I.E.E. TRANS., v. 48, April 1929, p. 629–30), which is, in ounce-feet,

$$T_{ss} = \frac{1.33 \times 10^{-8}}{0.637} p(2N_f)(-\Phi_aI_{2m} \cos \psi_1 + \Phi_mI_{2a} \cos \psi_2)$$

Rewriting this equation in a more suitable form for vector calculation,

$$T_{ss} = 11.3 \frac{p}{f} [X_{mm}(I_1 - I_{2m}) \text{ conj } I_{2a} - X_{ma}(I_1 - I_a - I_{2a}) \text{ conj } I_{2m}]$$

where the real terms alone give the average starting torque, and

T_{ss} = starting torque in ounce-inches
p = number of poles
f = frequency in cycles per second

PERFORMANCE CHARACTERISTICS

The shaded pole motor is very similar to a resistance split-phase motor in its performance characteristics. Typical performance curves are shown in figure 6. It is difficult to get much starting torque. However, it is generally used for fan duty for which a high value of starting torque is not necessary. It will have nearly double the watts input of a capacitor motor which does the same work. With such high losses, it is not surprising to find its power factor fairly high for such a small motor. The losses are very nearly constant from no load to maximum load.

For fan duty, these motors are usually worked very near to the breakdown point as shown by the typical speed-torque curve of the fan blade normally used with this motor. This usually gives the best efficiency and the most power that the motor will develop. The motor is inherently noisy and is usually subject to "cogging," that is, variation of starting torque with rotor position. To overcome these difficulties the motors ordinarily have larger air gaps, greater skew, and lower inductions than split-phase motors of similar ratings.

Variable speed is obtained by a series resistor or more often a "choke coil" or reactor. If speed change is desired, it is all the more necessary to operate the full speed point very near to breakdown.

As may be seen from the equations of appendix II, the calculation of running conditions is rather cumbersome, and in most cases not necessary. Very often the designer's problem is simply to obtain a motor to drive a certain fan at a specified speed. The usual method of procedure, unless a really extensive and thorough job is necessary, is to drive the blade with several different motors and by varying the voltage obtain readings of speed, watts, and amperes as shown in figure 7. These tests are known as "fan saturation tests." From the tests with the several motors, the amperes and watts are noted at the correct speed and the best motor is chosen. This motor is rewound or a new one built with the field turns changed in inverse proportion to the ratio of test voltage and normal voltage for the motor.

As may be seen from figure 7, the curve of speed versus volts has a typical saturation shape, that is, steep at first, then flattening off at the higher voltages, the maximum value being slightly less than synchronous speed. If the motor is to be single speed and it is desirable to have the speeds on production motors to be as nearly alike as possible, a motor is chosen from the tests which operates well up on the flat part of the curve.

However, if the fan is to operate at several speeds, the high speed point should not be too far above the knee of the curve so that too great voltage change will not be necessary to get speed change. In this case, it is not desirable for the part of the curve below the knee to be too steep. The slope of this portion is affected by starting conditions. A low starting torque motor is likely to have a steep speed-voltage curve, and a high starting torque motor usually has a more sloping curve with the knee less pronounced.

STARTING CONDITIONS

Starting conditions may be calculated without too much difficulty, and a considerable investigation of the effect of changing various parts of the motor has been made. The equations have been given hereinbefore, and a derivation of them is given in Appendix I. The effect of changing primary resistance and reactance is not shown, the effect of these changes being exactly the same as adding an external impedance which merely reduces the voltage on the motor. Of course, if series resistance is added, the loss in it must be added to the input to the motor on its reduced voltage to obtain the total input.

Figure 8 shows the effect of rotor resistance on the starting characteristics of a typical motor, which was the same one used for the tests illustrated by figures 5 and 6. It must be remembered that the watts and amperes shown on this and the following curves are under standstill or locked rotor conditions and not full load running conditions. The arrow shows the normal value for this motor. On most motors as well as this example it will be found that a rotor design of usual induction motor proportions ordinarily will be on the top part of the curve, and anything except radical changes in rotor resistance has little effect on the starting conditions.

Figure 9 shows the effect of the shading coil resistance. This effect is relatively pronounced. As a general rule, however, the decreased resistance which results in better starting torque usually results in much poorer running conditions and particularly in increased losses, so that a compromise must be made between them.

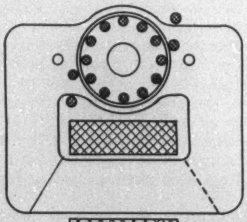


Fig. 4. Example of typical shaded pole motor construction

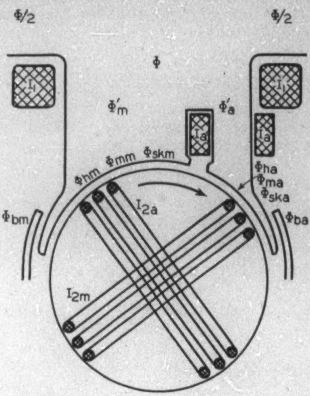


Fig. 5. Diagram of pole and rotor in shaded pole motor

It will be found in many cases that increasing the mutual flux of the primary and shading coil circuits which does not link the rotor will materially improve the starting conditions of the motor. Often it will also improve the running conditions and many shaded pole motors are now built with this in mind. This is done by providing a magnetic bridge between the shading pole and the next main pole. Figures 2, 3, and 4 show typical methods of doing this. Figure 10 shows the effect of the increased leakage on the starting conditions of this motor. In this case the improvement is quite marked.

One of the most difficult problems to investigate experimentally is the problem of how much to "shade" the motor, that is, what per cent of the total pole face should be used for the shaded pole. This again is a compromise between running conditions and starting conditions. The best over-all value lies between 0.25 and 0.50 for motors that must operate continuously at normal speeds, and often is arbitrarily chosen at $^1/_3$. However, figure 11 shows that motors for starting service only, such as motor operated valves, induction regulators, tap changers, etc., will probably be more satisfactory with a greater value of shading.

The effect of air gap change is much more difficult to show. The actual average starting torque with stator and rotor surfaces concentric and of an infinite number of rotor slots would probably vary with air gap change similar to the calculated curve of figure 12. (This curve is so closely proportional to the product K_{rm} K_{ra} that a single curve has been drawn.) However, because of inaccuracies of manufacture, air gaps are never quite perfect, and combined with a finite number of rotor slots cause a variation of starting torque with rotor position

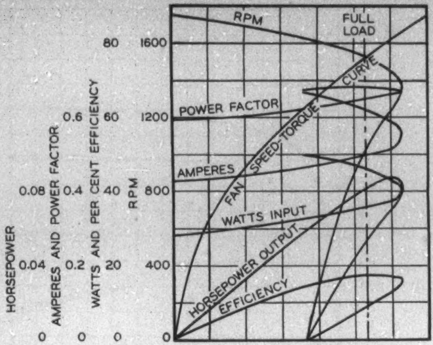


Fig. 6. Performance curves of a typical shaded pole motor

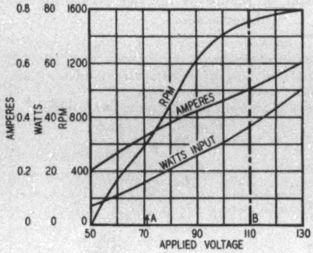


Fig. 7. Fan saturation curves of typical shaded pole fan motor

A—Minimum starting voltage

B—Normal voltage

that is ordinarily very pronounced with small air gaps. In addition, there will often be variation of bearing friction with different positions of the shaft. As a result, in all probability many production motors of the design used for figure 12 will vary in starting torque in different rotor positions between the limits shown by the 2 outer curves. These curves seem rather extreme, but actual cases seem to bear them out all too well. Thus, the minimum starting torque, which is after all the real criterion of the motor, will actually increase with the air gap up to a certain value.

Appendix I—Derivation of Shaded Pole Motor Equations at Standstill

The 4 equations which determine the performance of a shaded pole motor have been given. If the special case of the rotor at standstill is considered, the problem becomes much simpler. In this case $S = 0$, and the equations become

$$I_1[r_1 + j(x_1 + X_{mm} + X_{ma} + X_{a1})] - jI_a(X_{a1} + X_{ma}) - jI_{2m}X_{mm} - jI_{2a}X_{ma} = E$$

$$-I_1[j(X_{a1} + X_{ma})] + I_a[r_a + j(x_a + X_{a1} + X_{ma})] + 0 + jI_{2a}X_{ma} = 0$$

$$-I_1jX_{mm} + I_{2m}(r_2 + jX_{o2}) = 0$$

$$-I_1jX_{ma} + jI_aX_{ma} + I_{2a}(r_a + jX_{o3}) = 0$$

These equations will now be solved.

Secondary Current in the Main Phase

$$I_{2m} = \frac{I_1jX_{mm}}{r_2 + X_{o2}} = I_1\frac{X_{o2}X_{mm} + jr_2X_{mm}}{r_2^2 + X_{o2}^2}$$

$$I_{2m} = I_1\frac{\dfrac{X_{o2}X_{mm}}{X_{o2}^2} + jr_2\dfrac{X_{mm}}{X_{o2}^2}}{1 + (r_2/X_{o2})^2}$$

$$I_{2m} = I_1\frac{K_{rm}}{X_{mm}}(X_{o2} + jr_2)$$

where

$$K_{rm} = \frac{(X_{mm}/X_{o2})^2}{1 + (r_2/X_{o2})^2}$$

Secondary Current in the Auxiliary Phase

$$I_{2a} = (I_1 - I_a)\frac{jX_{ma}}{r_2 + jX_{o3}} = (I_1 - I_a)\frac{X_{ma}X_{o3} + jr_2X_{ma}}{r_2^2 + X_{o3}^2}$$

$$I_{2a} = (I_1 - I_a)\frac{\dfrac{X_{o3}X_{ma}}{X_{o3}^2} + jr_2\dfrac{X_{ma}}{X_{o3}^2}}{1 + (r_2/X_{o3})^2}$$

$$I_{2a} = (I_1 - I_a)\frac{K_{ra}}{X_{ma}}(X_{o3} + jr_2)$$

where

$$K_{ra} = \frac{(X_{ma}/X_{o3})^2}{1 + (r_2/X_{o3})^2}$$

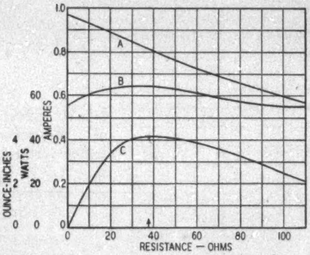


Fig. 8. Effect of rotor resistance on starting characteristics

Curve *A*—Locked current

Curve *B*—Locked input power

Curve *C*—Locked torque

Arrow indicates normal value

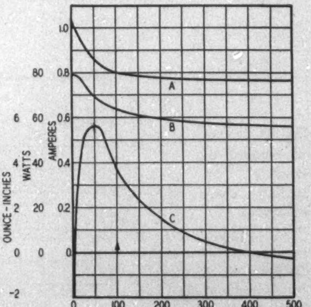


Fig. 9. Effect of shading coil resistance on starting characteristics

Curve designations same as in figure 8

Arrow indicates normal value

Shading Coil Current

$$I_1[r_1 + j(x_1 + X_{mm} + X_{ma} + X_{a1})] - jI_a(X_{a1} + X_{ma}) -$$
$$jX_{mm}I_1 \frac{K_{rm}}{X_{mm}} (X_{02} + jr_2) - jX_{ma}(I_1 - I_a) \frac{K_{ra}}{X_{ma}} (X_{03} + jr_2)$$
$$= E - I_1[j(X_{a1} + X_{ma})] + I_a[r_a + j(x_a + X_{a1} + X_{ma})] +$$
$$jX_{ma}(I_1 - I_a) \frac{K_{ra}}{X_{ma}} (X_{03} + jr_2) = 0$$

$$I_1[r_1 + j(x_1 + X_{mm} + X_{ma} + X_{a1}) - jK_{rm}X_{02} + K_{rm}r_2 -$$
$$jK_{ra}X_{03} + r_2K_{ra}] - I_a[j(X_{a1} + X_{ma}) - jK_{ra}X_{03} + K_{ra}r_2]$$
$$= E - I_1[j(X_{a1} + X_{ma}) - jK_{ra}X_{03} + r_2K_{ra}] +$$
$$I_a[r_a + j(x_a + X_{a1} + X_{ma}) - jK_{ra}X_{03} + r_2K_{ra}] = 0$$

$$I_a = I_1 \frac{r_2K_{ra} + j(X_{a1} + X_{ma} - K_{ra}X_{03})}{(r_a + r_2K_{ra}) + j(x_a + X_{a1} + X_{ma} - K_{ra}X_{03})}$$

Let

$$X_4 = X_{a1} + X_{ma} - K_{ra}X_{03}$$

$$I_a = I_1 \frac{r_2K_{ra} + jX_4}{(r_a + r_2K_{ra}) + j(X_a + X_4)}$$

Primary Current

$$I_1[(r_1 + r_2K_{rm} + r_2K_{ra}) + j(x_1 + X_{mm} - K_{rm}X_{02}) +$$
$$j(X_{a1} + X_{ma} - K_{ra}X_{03})] - I_1 \frac{(r_2K_{ra} + jX_4)(r_2K_{ra} + jX_4)}{(r_a + r_2K_{ra}) + j(x_a + X_4)} = E$$

Let $Z_L = E/I_1$ and $X = x_1 + X_{mm} - K_{rm}X_{02}$

Then $I_1 = E/Z_L$

$$Z_L = (r_1 + r_2K_{rm} + r_2K_{ra}) + j(X + X_4) -$$
$$\frac{(r_2K_{ra} + jX_4)^2}{(r_a + r_2K_{ra}) + j(X + X_4)}$$

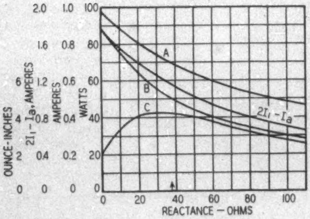


Fig. 10. Effect of magnetic bridge reactance on starting characteristics

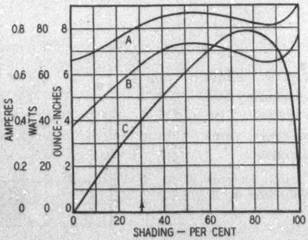
Curve designations same as in figure 8

Arrow indicates normal value

Fig. 11. Effect of amount of shading on starting characteristics

Curve designations same as in figure 8

Arrow indicates normal value



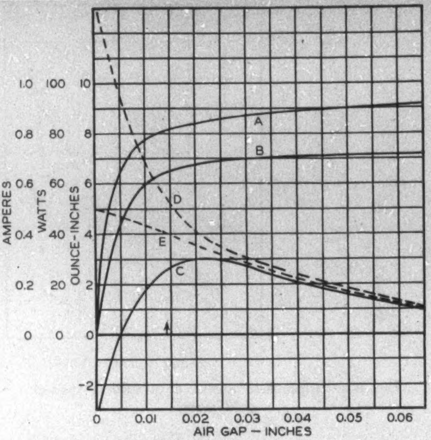


Fig. 12. Effect of length of air gap on starting characteristics

Curve *A*—Locked current
Curve *B*—Locked input power
Curve *C*—Probable minimum or useful locked torque
Curve *D*—Probable maximum locked torque
Curve *E*—Theoretical average locked toque (proportional to $K_{rm}K_{ra}$)
Arrow indicates normal value

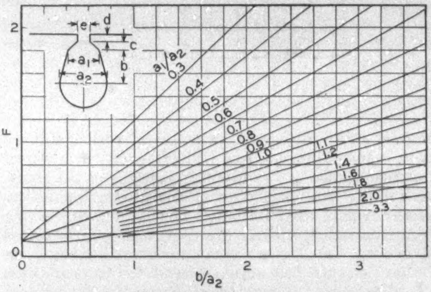


Fig. 13. Curves for obtaining slot leakage constant for primary

$$K_s = F + \frac{d}{e} + \frac{2c}{e + a_1}$$

$$Z_L = r_1 + r_2K_{rm} + jX + \frac{(r_a + jX_a)(r_2K_{ra} + jX_4)}{(r_a + r_2K_{ra}) + j(X_a + X_4)}$$

"F" Constants. For simplicity of calculation, let

$$F_1 = \frac{r_2K_{ra} + jX_4}{(r_a + r_2K_{ra}) + j(X_a + X_4)}$$

$$F_2 = \frac{K_{rm}}{X_{mm}} (X_{02} + jr_2)$$

$$F_3 = \frac{K_{ra}}{X_{ma}} (X_{03} + jr_2)$$

Then the 4 current equations become

$I_1 = E/Z_L$ where $Z_L = (r_1 + r_2K_{rm}) + jX + Z_aF_1$

$I_a = I_1F_1 \quad I_{2m} = I_1F_2 \quad I_{2a} = (I_1 - I_a)F_3$

Fluxes in Each Part of the Circuit

$$\Phi_{mm} = -j\frac{e_{mm}\,45 \times 10^6}{f\ C}$$

$$e_{mm} = j(I_1 - I_{2m})X_{mm}$$

$$\Phi_{mm} = (I_1 - I_{2m})X_{mm}\frac{45 \times 10^6}{f\ C}$$

$$e_{ma} = j(I_1 - I_a - I_{2a})X_{ma}$$

$$\Phi_{ma} = (I_1 - I_a - I_{2a})X_{ma}\frac{45 \times 10^6}{f\ C}$$

$$\Phi_1 = I_1x_1\frac{45 \times 10^6}{f\ C}$$

$$\Phi_{a1} = (I_1 - I_a)X_{a1}\frac{45 \times 10^6}{f\ C}$$

$$\Phi_b = (I_1 + I_1 - I_a)X_b\frac{45 \times 10^6}{f\ C}$$

Starting Torque. In his discussion already referred to, C. R. Boothby gives an equation for starting torque in ounce-feet[*] as follows:

$$T_{ss} = \frac{1.33 + 10^{-8}p(2N_f)}{0.637}(-\Phi_{ma}I_{2m}\cos\psi_1 + \Phi_{mm}I_{2a}\cos\psi_2)$$

Changing to ounce-inches,

$$T_{ss} = 25.2 \times 10^{-8}pC(-\Phi_{ma}I_{2m}\cos\psi_1 + \Phi_{mm}I_{2a}\cos\psi_2)$$

If Φ and I are in vectors, it is usually easier to obtain the average real torque by the real terms of

$$(-\Phi_{ma}\operatorname{conj} I_{2m} + \Phi_{mm}\operatorname{conj} I_{2a})$$

$$T_{ss} = 25.2 \times 10^{-8}pC\frac{45 \times 10^6}{f\ C}(X_{mm}(I_1 - I_{2m})\operatorname{conj} I_{2a} - X_{ma}(I_1 - I_a - I_{2a})\operatorname{conj} I_{2m})$$

$$T_{ss} = \frac{11.3p}{f}[X_{mm}(I_1 - I_{2m})\operatorname{conj} I_{2a} - X_{ma}(I_1 - I_a - I_{2a})\operatorname{conj} I_{2m}]$$

where only the real terms are used. In this equation

T_{ss} = starting torque in ounce-inches
p = number of poles
f = frequency in cycles per second

Positive torque is in the direction from main pole to shaded pole.

Appendix II—Calculation of Motor Constants

Formulas have been derived for the motor constants in terms most familiar to induction motor designers. Space does not permit the complete derivations to be given, and only the final results will be listed. In all cases, the secondary impedances are given referred to the primary.

RESISTANCES

Primary Resistance. This resistance (r_1) a straightforward calculation from the length of wire used.

Shading Coil Resistance. For a copper coil at 25 degrees centigrade

$$r_a = 1.385\frac{lmc_a}{S_a}N_2p(C/Ca)^2 10^{-6}$$

where

lmc_a = length of mean conductor of shading coil ($^1/_2$ turn)
S_a = section of shading coil in square inches
N_2 = shading coil turns per pole
p = number of poles
C_a = total number of shading coil conductors

Rotor Resistance. The rotor resistance will be the same as for any squirrel cage rotor.

$$r_2 = \left(\frac{\sqrt{W^2 + SK^2}}{S_cS_s} + \frac{0.637D_r}{S_rp^2}\right)1.385C^2 10^{-6}$$ for copper bars and rings at 25 degrees centigrade

where

W = stacking or axial width of rotor
SK = skew of rotor in inches
S_c = section of rotor conductor in square inches
S_s = number of rotor conductors
S_r = section of resistance ring in square inches
D_r = diameter at which conductors enter the ring

REACTANCES

The reactance voltages induced by the motor fluxes will be separated into several components, and each component reactance calculated separately. Let

X_{mm} = reactance of fundamental mutual main-field air-gap flux
X_{ma} = reactance of fundamental mutual shaded-field air-gap flux
X_{hm} = reactance of harmonics of main-field air-gap flux
X_{ha} = reactance of harmonics of shaded-field air-gap flux
X_{skm} = reactance caused by skewing through main field flux
X_{ska} = reactance caused by skewing through shaded field flux
X_{bm} = X_{ba} = reactance of magnetic bridge or pole tip flux not linking the rotor conductors
x_1' = reactance of primary coil leakage flux
x_a = reactance of shading coil leakage flux
x_2 = reactance of rotor leakage flux

Magnetizing Reactances. The reactance caused by the rectangular wave of air gap flux under the pole face will be determined first, then it will be divided into 3 components: the fundamental sine

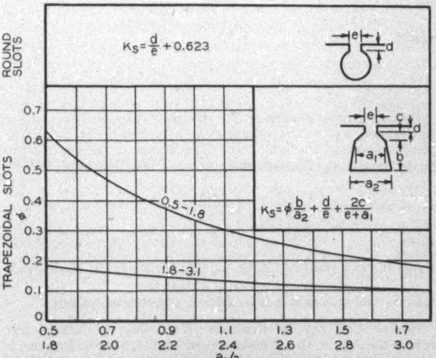


Fig. 14. Curves for obtaining slot leakage constant for shading coil

wave, the sum of the harmonics, and that part of the fundamental lost through skewing.

Total reactance of flux under pole face:

$$X = (2\pi f C^2 10^{-8}) \frac{3.19 W \lambda_p}{4 l_g p} \alpha$$

where

l_g = effective length of air gap, accounting for slot openings and saturation of iron
f = frequency
p = number of poles
C = total primary conductors (double the number of turns)
W = stacking or axial width of the rotor and stator
λ_p = pole pitch in inches
α = effective pole face

Reactance of Fundamental Sine Wave of Flux

$$X_m = 2\pi f C^2 10^{-8} \left(\frac{0.647 W \lambda_p}{l_g p} \sin^2 \beta/2 \right)$$

where β is the effective pole face in electrical degrees.

Harmonic Reactance. The harmonic reactance is here defined as the magnetizing or mutual reactance. However, the total reactance of the primary must be that of the rectangular wave of flux. The difference, therefore, must be leakage, and this is defined as harmonic leakage reactance.

$$X_h = 2\pi f C^2 10^{-8} \left(\frac{0.647 W \lambda_p}{l_g p} \sin^2 \beta/2 \right) C_h$$

where

$$C_h = 1.232\alpha - \sin^2 \beta/2$$

Skew Leakage. The introduction of the effect of skewing as a term in the leakage reactance is due to C. G. Veinott of the Westinghouse Electric and Manufacturing Company, although it is used here in a slightly different manner.

It can be shown that the magnetizing reactance will be slightly reduced by skewing, and a corresponding amount of reactance must be added as leakage. This has a slight effect on the magnetizing and harmonic reactances as calculated above

$$X_m = 2\pi f C^2 10^{-8} \left(\frac{0.647 W \lambda_p}{l_g p} \sin^2 \beta/2 \right) C_{sk}$$

$$X_{sk} = X_m \frac{(1 - C_{sk})}{C_{sk}}$$

$$X_h = X_h \frac{C_h}{C_{sk}}$$

where

$$C_{sk} = \frac{\sin \Theta_{sk}/2}{\Theta_{sk}/2}$$

Primary Leakage Reactance. The primary leakage can be calculated in the same way as the leakage of an induction motor slot, if the tooth tip leakage flux is omitted. The leakage at the coil end will be the usual case of end leakage.

$$x_1' = 2\pi f C^2 10^{-8} \left(\frac{3.19 W}{2p} K_s + \frac{span}{p} \right)$$

where

K_s = "slot constant" such as found from figure 13 or figure 14 omitting the tooth-tip leakage flux
$span$ = coil span in inches, based on a semicircular coil end

Shading Coil Leakage Reactance. Neglecting the leakage flux around the side of the shading coil which lies outside the pole, a similar formula to that for the primary coil is obtained.

$$x_a = (2\pi f C^2 10^{-8}) \left(\frac{3.19 W}{4p} K_s + \frac{span}{p} \right)$$

Rotor Leakage Reactance. The rotor leakage reactance x_2 has been divided into 3 components:

$$X_{\text{slot}} = 2\pi f C^2 10^{-8} \frac{6.38 W}{S_s} K_s$$

$$X_{\text{zigzag}} = 2\Phi f C^2 10^{-8} \frac{6.38 W}{S_s} \frac{T_f''/2}{2\Delta}$$

$$X_{\text{skew}} = X_m \frac{1 - C_{sk}}{C_{sk}}$$

where

S_s = number of rotor slots
T_f'' = rotor tooth face in inches

Reactance of the pole tip or magnetic bridge flux is by far the most difficult to calculate accurately. The pole tip reactance may be approximated by the following formula (figure 15)

$$X = 2\pi f C^2 10^{-8} \left(\frac{3.19 W}{4p} \frac{d_1}{e_1} \right)$$

The magnetic circuit of the bridge flux consists of 2 parts in series. There is the bridge itself, and, in most cases, an air gap at each end where the bridge rests on the pole tips. A cut-and-try method of assuming flux and calculating ampere-turns must be used until the sum of iron and gap ampere-turns equals the magnetomotive force of the circuit, $(C/2p)(2I_1 - I_a)$.

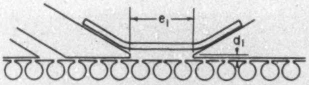


Fig. 15. Pole tip or bridge flux paths

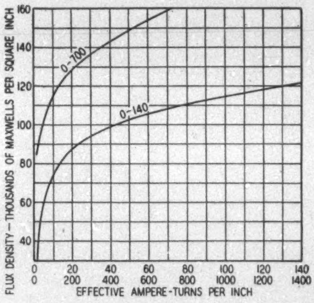


Fig. 16. Typical saturation curve used for calculating magnetic bridge reactance

Figure 16 is a typical magnetic saturation curve which can be used for the bridge iron ampere-turns, and the ampere-turns of the 2 series air gaps equal

$$\Phi \frac{0.313}{2} \frac{2 l_g}{A_g}$$

where

l_g = length of gap
A_g = area of gap
Φ = flux

The reactance of the bridge flux is

$$X_b = \frac{\Phi f C}{45 \times 10^{8}(2I_1 - I_a)} = \frac{\Phi f C^2}{45 \times 10^{8} 2p(mmf)}$$

Switchboards and Signaling Facilities of the Teletypewriter Exchange System

The development of a nationwide teletypewriter transmission system in the United States required the design of switchboards and signaling facilities adapted to this special service. The 2 types of switchboard now in use are described in this paper, and the operation of the circuit by means of which connections are established between the various subscribers and supervised by the operators is explained.

By
A. D. KNOWLTON
MEMBER A.I.E.E.

G. A. LOCKE
ASSOCIATE A.I.E.E.

F. J. SINGER
ASSOCIATE A.I.E.E.

Bell Tel. Labs., Inc.,
New York, N. Y.

A NATIONWIDE teletypewriter service giving direct connection between subscribers for the exchange of written messages by means of the teletypewriter, in a manner similar to the service offered by the telephone system for the exchange of spoken messages, was offered to the public as a new aid to business by the Bell System on November 21, 1931. This service, known as the teletypewriter exchange (*TWX*) service, introduced a switching technique which, although familiar in the telephone art, involved many new technical problems when applied to the telegraph art.

Records show that during the nineteenth century some telegraph exchanges were established at which connections could be made on a message basis for to and fro telegraph communications between subscribers. These earlier exchanges had a commercial appeal although the various forms of subscriber instruments then used were slow and required considerable skill for operation. Later, when the telephone was introduced, these exchanges gradually disappeared because the public naturally preferred the more convenient instrument. With the introduction of the modern teletypewriter the telegraph exchange idea was again revived because the teletypewriter, being very similar to an ordinary typewriter and permitting an accurate written record of a to and fro communication, has, from a subscriber standpoint. overcome the objectional features of the early telegraph instruments.

The private line telegraph and teletypewriter service furnished by the Bell System has formed a very important background for the new teletypewriter exchange service. The older service, which provides relatively permanent networks interconnecting various stations in a predetermined manner for a predetermined time, has been available to the public since about 1890. During the earlier period it was used chiefly by the press and brokers and was operated on a Morse telegraph basis, generally using composite or simplex line facilities. Later, with the introduction of the modern teletypewriter, the carrier telegraph, and other improvements, together with the growth of American business and the demand for rapid and accurate written communications, this private line business expanded rapidly and service was furnished not only to the press and brokers but also to other financial institutions, manufacturers, government bureaus, police departments, and a wide variety of retailers and distributors of goods. This business has become nationwide. Many of these private line systems are provided with switching facilities for use by the customer in each system, although the supervisory arrangements are rather elementary.

In addition to the private line telegraph service and the arrangements which had been developed and applied to that service, the many developments in the telephone field formed an important contribution to the teletypewriter exchange service. It is obvious that in providing *TWX* service, which is a point-to-point service with connections set up and taken down on the subscriber's order, use can be made of many traffic and service practices used in the telephone service. Furthermore, certain telephone apparatus such as switching relays, cords, plugs, etc., can be employed to advantage.

With this background, when it was decided to furnish a nationwide teletypewriter exchange service to the public, Bell System engineers had the problem of determining what general plan of design to adopt. There were 2 alternatives: (1) to provide a service using the telephone plant and existing telephone switchboards, or (2) to provide separate switchboards for use with the telegraph plant. The important advantages of the first plan are:

(*a*). The switchboards and signaling arrangements designed for and in use in the telephone plant could be employed.

(*b*). The same operating groups handling the telephone service would handle this service. Inasmuch as telephone service is on a 24 hour basis throughout the country, the *TWX* service could be furnished on the same basis with a relatively low operating cost.

The disadvantages of the first plan are:

(*a*). Because the teletypewriter operates on a d-c basis it would be necessary to provide an oscillator and associated apparatus at

---

A paper recommended for publication by the A.I.E.E. committee on communication, and scheduled for discussion at the A.I.E.E. South West District meeting, Dallas, Texas, October 26–28, 1936. Manuscript submitted July 17, 1936; released for publication August 11, 1936.

Fig. 1. Number 1 teletypewriter switchboard at New York, N. Y.

the station to generate an audio frequency alternating current for modulation by the signals sent by the teletypewriter, and a rectifier to convert the a-c pulses received from the distant station to d-c pulses for operation of the receiving mechanism of the station teletypewriter. Furthermore, it would be necessary to furnish a telephone instrument at the station to permit the subscriber to communicate with the operator unless a teletypewriter or other type of recording instrument were provided at each operating position.

(*b*). Relatively expensive telephone lines known as intertoll trunks would be required between central offices. If the cheaper telegraph channels were used as intertoll trunks it would be necessary to provide frequency converters at each terminal to translate the frequency band required on the subscriber loop to a band suitable for application to the telegraph intertoll trunks. If the telegraph channels were used between switchboards it would also be necessary to provide the operators with teletypewriters or other means of communication because the telegraph channels do not permit oral communication.

(*c*). A number of miscellaneous engineering and plant problems other than those listed in (*a*) and (*b*) would be introduced if standard telephone facilities were used to interconnect the stations in the teletypewriter exchange network.

After due consideration of all these factors it was decided to utilize the telegraph plant and to design and provide the necessary teletypewriter switchboards and interoffice signaling arrangements. By following this plan it has been possible to establish service on a nationwide basis using switchboards at the larger switching centers and employing modified telegraph private wire testboards at the smaller centers.

This paper describes the signaling and switching arrangements used in the present system, and particularly the 2 principal types of switchboards that are in use. The discussion is limited to the most important signaling and switching arrangements, as the transmission features are described in another paper.[1] A description is included of the principal factors entering into the design of the more important circuits used in these switchboards; the subscriber lines, intertoll trunks, and cords. The subscriber line treatment is divided into 3 broad classes: local subscribers having either attended-only or unattended service; distant subscribers served over telegraph toll line facilities; and distant subscribers served over telephone facilities. Particular attention is given to the fundamental problem of providing supervisory signals over the telegraph lines used as intertoll trunks in the interoffice connections.

TELETYPEWRITER SWITCHBOARDS

To reach subscribers in all parts of the country there has been established a network of teletypewriter switching points interconnected by telegraph lines. At each of the larger switching points a teletypewriter switchboard is provided, the principal switchboards being the number 1 teletypewriter switchboard having a capacity of 3,600 subscriber lines, and the number 3*A* teletypewriter switchboard having a capacity of 1,200 subscriber lines. The former, a general view of which is shown in figure 1, is used at large cities such as New York and Chicago, while the latter, a general view of which is shown in figure 6, is used at smaller cities such as Pittsburgh and Kansas City.

Fundamentally, a manual switchboard consists of 2 parts: the terminations for subscribers lines and intertoll trunks, and the switching facilities used by the operators in interconnecting the lines and trunks. The line and trunk terminations are in the form of multiple jacks and lamps located in the jack field and are accessible to all operators. The switching facilities, or cords, together with the means for communication to subscribers or other operators, are individual to each operator and are, in general, located at the keyshelf. Although the design of the switching equipment and the multiple are to some extent dependent upon each other, the principal factors influencing the design are, for the purpose of discussion, considered independently.

Number 1 Teletypewriter Switchboard Position Equipment. The number 1 teletypewriter switchboard position consists essentially of a teletypewriter for the operator's use in sending and receiving the instructions for establishing the connections, together with a number of cords for making the various interconnections between the line terminations. The number of these cords necessary for the efficient

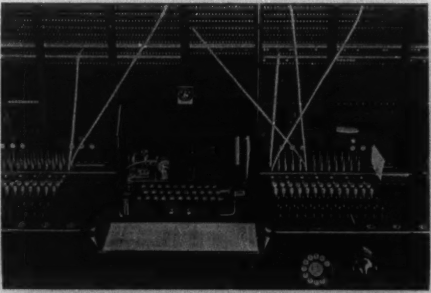


Fig. 2. Keyshelf arrangement of number 1 teletypewriter switchboard

---

1. For numbered reference see end of paper.

functioning of an operator is the most important factor governing the width of the position, a primary consideration in the design of a switchboard.

The number of cords per operator is dependent on the average time required to set up and disconnect each call (known as the average work time per call) and the average communication time per call. Whereas the former can be forecast quite accurately by the operating characteristics of the circuits, the latter is dependent on the commercial application of the service. To insure the provision of an adequate number of cords it was necessary to allow for the longest average communication time which could be reasonably anticipated. The analysis of the average work time per call together with the forecast communication time resulted in the requirement being set up for a maximum of 18 cords per operator.

With the requirement for the position equipment established at 18 cords (and one teletypewriter for communication purposes), the width of the position was determined to be approximately 34 inches or the width of 4 panels of the jack field, each panel being $8^{1}/_{2}$ inches in width. The division into an even multiple of panels is for constructional purposes, to separate the switchboard into sections for manufacturing. It was, however, necessary to adopt a new type of keyshelf construction, shown in figure 2, to provide for the operator's teletypewriter.

Because of its large size, the teletypewriter was located as low as possible to minimize blocking the jack field. This required the provision of a teletypewriter shelf the lower edge of which was at the same height as the lower edge of the adjacent keyshelves. The depth of the teletypewriter made it necessary to recess it in the jack field. This recess was obtained by cutting off one stile strip and adding a longitudinal detail the entire width of the section to support the lower end of the cut stile strip. The teletypewriter shelf was placed on rollers to permit its sliding out easily for maintenance accessibility.

The teletypewriter, being the operating center of the position, has 9 cords on each side, placing all 18 cords within easy reach of the operator. Because of this arrangement it was not possible to make the position boundaries coincide with the section boundaries as this would require 2 keyshelves of 9 cords each per section with the consequent waste of equipment space for the supports between adjacent keyshelves. This loss of space was reduced by providing one 18 cord keyshelf per 2 position section and associating one half of the cords with the teletypewriter to the left and the other half with the teletypewriter to the right. This caused an overlap of the position and section boundaries so that the 9 cords on the left end of each section form a part of the right position of the adjacent section to the left.

Number 1 Switchboard Multiple Equipment. The primary objective in the design of multiple equipment is the provision of line terminations in a form that will make each line readily accessible to every operator, taking into consideration the physical limitations imposed by the operator's reach. Previous experience in the design of telephone switchboards has determined that, for a subscriber switchboard, satisfactory operating conditions may be obtained in respect to the horizontal reach of the operator by the multipling of the line terminations on an 8 panel basis (using the standard $8^{1}/_{2}$ inch panel) giving a distance of 68 inches from one appearance of a line to the next. The maximum reach in each horizontal direction will then be half of this distance, or 34 inches. This was, however, reduced to a 6 panel multiple giving a maximum reach of $25^{1}/_{2}$ inches to insure operating efficiency.

In determining the maximum vertical reach for the operator, the standard practice was followed of limiting this reach to 30 inches for line terminations which are to be answered, and to 34 inches for lines to which calls are to be completed. The line terminations to be answered by the operator are kept lower than the lines for completing purposes because the operator's attention must be attracted to the line by the illumination of the line lamp. The line capacity of the switchboard is limited by the number of line terminations that can be provided within the above dimensions.

The lower line of figure 3 shows the intertoll trunk and subscriber line capacities obtainable within the permissible reach limits on a 6 panel multiple basis where the complete subscriber multiple is equipped with answering lamps. The capacity shown is based on various ratios of subscriber lines to intertoll trunks. Because of the essentially toll character of the teletypewriter exchange service, it was anticipated that there would be a high ratio of intertoll trunks to subscriber lines and comparatively little local traffic. The traffic studies indicated that the average ratio would be in the order of 7 or 8 subscriber lines to one trunk. It may be seen from figure 3 that, with this ratio, a capacity of only 2,200 subscriber lines is obtainable with the entire multiple equipped with answering lamps.

By providing answering lamps for only the first half of the subscriber lines and installing the second half without answering lamps in the upper portion, the total space for a given number of lines can be reduced and advantage taken of the additional space afforded by the 34 inch vertical reach permissible for calling multiple. This arrangement, known as the inverted multiple, provides answering facilities for the second half of the subscriber lines in a second line-up of switchboard in which they are equipped with answering lamps. The first half of the lines also are multipled in this line-up but on a calling-only basis; that is, without lamps. With this arrangement, calls originated by the first half of the sub-

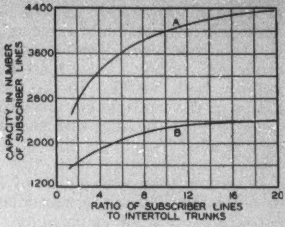


Fig. 3. Curves showing variation of subscriber line capacity for number 1 teletypewriter switchboard

A—Inverted multiple

B—Conventional multiple

scribers are answered in the first line of switchboard, and those originated by the second half are answered in the second line. Any operator may complete a connection to any line as there is a full multiple of jacks in both boards. In the second line-up the 2 halves of the multiple are inverted as to location in order to place the lines with answering lamps within easy reach. The upper line of figure 3 shows the capacities obtainable with this arrangement. It may be seen that, with a ratio of 7.5 subscriber lines to one intertoll trunk, a subscriber line capacity of approximately 3,800 is possible. It was necessary, however, to reduce this to 3,600 lines in order to obtain a division in a multiple of 600 lines to simplify the numbering of the jacks. With this arrangement 300 lines are provided in each panel without answering lamps and 300 lines with answering lamps.

This multiple arrangement is illustrated in figure 4, which shows schematically the cabling for the first half of the subscriber multiple (lines 0 to 1,799). It may be noted that a third line of switchboard, the inward and through board, is provided. Experience has shown that the most efficient operation is obtained if the inward and through traffic is segregated when the switchboard grows to 30 or more positions. As the subscriber multiple is used here for calling purposes only, the answering lamps can be omitted from the entire subscriber multiple, thus making additional space available for increased intertoll trunk capacity as discussed in the following. The subscriber lines are cabled from the main distributing frame (*MDF*) to the relay equipment and from there to the *TWX* intermediate distributing frame. Here cross connections are provided to permit the assignment of any subscriber line relay equipment to any multiple jack for flexibility in assigning numbers. The distributing frame terminal strip also serves as a doubling-up point for the cable to the switchboards.

A somewhat similar arrangement used for the intertoll trunk multiple is shown schematically in figure 5. The standard telegraph line facilities and terminating repeaters designed for private line service are used for the *TWX* trunks. Connections to these trunks are made at the test board distributing frame and the trunks are cabled to the *TWX* distributing frame. Here arrangements are provided for inserting a single line repeater, which is necessary for converting the positive and negative 130 volt signals to positive and negative 48 volt signals for transmission through the switchboard. The trunk is then carried to the teletypewriter test board where a termination is provided for the purpose of testing the equipment. From the test board the trunk is cabled through the relay equipment to the distributing frame, where it is cross-connected to the switchboard multiple, the multiple for all 3 lines of switchboard being doubled up at the distributing frame terminal strips. Ordinarily, with the inverted subscriber multiple arrangement, there will be a capacity for 480 intertoll trunks equipped with answering lamps in the first 2 lines of switchboard. However, opportunity is provided for increasing this capacity by the provision of the separate inward and through switchboard. As described above, the lamps in this inward board may be omitted from the subscribers' multiple. This arrangement provides sufficient space for the installation of 840 trunks equipped with answering lamps. As all trunks are answered at the separate inward switchboard, the answering lamps may be removed from the trunk multiple in the 2 outward switchboards, thereby releasing sufficient space for the full 840 trunks without the answering lamps.

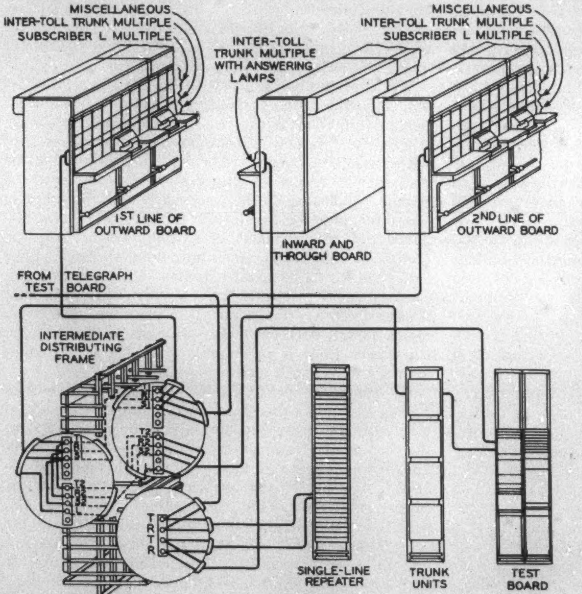

MISCELLANEOUS
INTER-TOLL TRUNK MULTIPLE
SUBSCRIBER L MULTIPLE
INTER-TOLL TRUNK MULTIPLE WITH ANSWERING LAMPS
MISCELLANEOUS
INTER-TOLL TRUNK MULTIPLE
SUBSCRIBER L MULTIPLE
1ST LINE OF OUTWARD BOARD
INWARD AND THROUGH BOARD
2ND LINE OF OUTWARD BOARD
FROM TEST
TELEGRAPH BOARD
INTERMEDIATE DISTRIBUTING FRAME
T
R
T
R
SINGLE-LINE REPEATER
TRUNK UNITS
TEST BOARD

Fig. 4. Diagram of cabling for subscriber lines on number 1 teletypewriter switchboard

Number 3A Teletypewriter Switchboard. The design of a switchboard for the medium sized *TWX* switching points was not undertaken until the system had been in operation for about 2 years, temporary switching facilities having been used at these points in the meantime. Actual operating experience and traffic data were then available upon which to base the design of the switchboard, a general view of which is shown in figure 6.

Efficient design requires that the width of a position be kept as small as possible to avoid the excessive cost of a long switchboard multiple. Because the smaller capacity required for this switchboard did not make the vertical reach an important factor, a keyshelf arrangement different from that used for the number 1 switchboard was adopted.

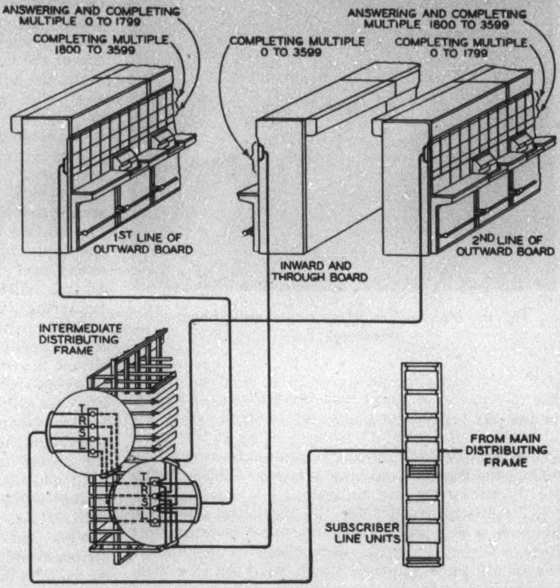

ANSWERING AND COMPLETING MULTIPLE 0 TO 1799
COMPLETING MULTIPLE 1800 TO 3599
COMPLETING MULTIPLE 0 TO 3599
ANSWERING AND COMPLETING MULTIPLE 1800 TO 3599
COMPLETING MULTIPLE 0 TO 1799
1ST LINE OF OUTWARD BOARD
INWARD AND THROUGH BOARD
2ND LINE OF OUTWARD BOARD
INTERMEDIATE DISTRIBUTING FRAME
T
R
S
L
T
R
S
L
FROM MAIN DISTRIBUTING FRAME
SUBSCRIBER LINE UNITS

Fig. 5. Diagram of cabling for intertoll trunks on number 1 teletypewriter switchboard

Instead of placing the teletypewriter and cords on the same level as in the number 1 switchboard, the cords are placed above the teletypewriter. This was accomplished by the use of a sloping keyshelf permitting the cords to pass by the teletypewriter in the manner shown by the cross-sectional view in figure 7. With the object of keeping the vertical height of the keyshelf as small as possible, the cords are located in a single horizontal row instead of in the conventional double row. With this arrangement, the answering cord is the left cord of a pair and the calling cord is the right cord. Differentiation is obtained by using colored plug shells, black for the answering cord and red for the calling cord.

An additional feature resulting from this relation of the keyshelf to the teletypewriter is an arrangement whereby the position may be adjusted to include various numbers of cords. This flexibility is obtained by the location of the teletypewriter on a table separate from the switchboard, the connections being made by a flexible plug-ended cord. This permits the location of the teletypewriter in front of any group of cords. A position jack is provided in each section which affords facilities for operators spaced on minimum centers of $20^{1}/_{2}$ inches, each operator having access to a maximum of 10 cords. This represents the closest centers which can be obtained with sufficient physical room for operating. Although the switchboards are usually engineered on the more ample operating centers of about $25^{5}/_{8}$ inches, the design permits the reduction of these centers to the $20^{1}/_{2}$ inch dimension in the event that more operators are required for unexpected increases in traffic. If traffic conditions change or the inward and through traffic is segregated, thus necessitating positions equipped with more cords, the width of the position can be increased to include the number of cords required.

The switchboard is divided into sections, each having 2 panels and each arranged for a position circuit. The section is an arbitrary division of the switchboard for constructional purposes and has no bearing on the position boundaries. All keys and cords in a section are terminated on terminal strips in the rear. The cord relay equipment is furnished in units of 10 circuits, each unit being equipped with terminal strips so located that, when a unit is placed in the rear of a section, the terminal strips come directly under the section terminal strips. Distributing rings above the 2 rows of terminal strips provide facilities which permit any relay equipment to be cross-connected to any keyshelf cord equipment.

The engineering of this switchboard is thus reduced to a very simple process. The number of cords required per operator is determined by the anticipated traffic data. From this information the width of each position is determined. The sum of the positions required to handle the peak load represents the total length of the switchboard and determines the total number of sections required. Cord units are then provided in the rear of the switchboard. The cords required for each position are then cross-connected to relay circuits on the cord units which are in turn cross-connected to the nearest position circuit. Teletypewriters are moved in front of the various groups of cords and plugged into the jacks for their position circuits. Should conditions require a different assignment of cords, they may be recross-connected to meet the new requirements and the teletypewriters moved to new positions.

Number 3A Switchboard Multiple Equipment. For convenience, the operator's vertical reach for lines with answering lamps has been defined as 30 inches above the standard type of keyshelf. From the lower edge of the keyshelf, which prevents the operator from rising to reach further, the permissible reach is 35 inches. Deducting the space required for

Fig. 6. Number 3A teletypewriter switchboard at Pittsburgh, Pa.

the teletypewriter and keyshelf equipment, there remains $14^1/_2$ inches available for multiple below the 35 inch reach limit. About $2^5/_8$ inches of this space is required for unattended line terminations and miscellaneous multiple, leaving a space of $11^7/_8$ inches for the subscriber line multiple.

This space provides for the capacities shown in figure 8, which are in terms of ratios of subscriber lines to intertoll trunks. This chart is based on the use of a 6 panel multiple which, with the $10^1/_4$ inch panel required for the type 49 jack used, results in a horizontal reach of $30^3/_4$ inches. It may be seen that with a ratio of 7.5 subscriber lines to one trunk a capacity of about 1,300 lines is obtainable. Because the ratio of trunks to subscriber lines is somewhat greater on small switchboards than on the larger boards, because of the relative inefficiency of smaller trunk groups, the multiple is designed on the basis of 1,200 subscriber lines and 240 intertoll trunks which gives a ratio of 5 subscriber lines to one trunk.

CIRCUIT FUNCTIONS

The foregoing paragraphs have given a picture of the physical arrangement of the more important switchboards, and an idea of the number of subscriber lines and intertoll trunks that can be accommodated by each. Some idea must also be given of the circuit methods by means of which connections are established between the various subscribers and supervised by the operators.

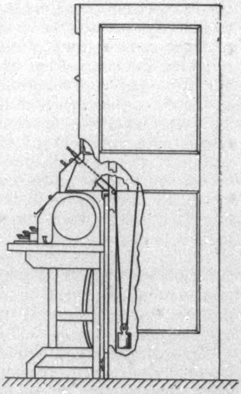
Subscriber Station and Station Circuit. The basic instrument by means of which the subscriber sends and receives his message is the teletypewriter. It is not proposed to give here a description of the teletypewriter as this is discussed in other papers. Other equipment, however, is required in addition to the teletypewriter to provide for the necessary signaling facilities for the exchange service.

A typical installation in a subscriber's office is shown in figure 9. The arrangement shown provides for the number 15 (page) teletypewriter, used predominantly in the *TWX* service, mounted on a table which has been designed to provide adequate mounting facilities for the signaling equipment. This table is arranged with a removable panel known as a control panel, which is mounted in an opening in the top of the table to the right of the teletypewriter to make the key levers readily accessible to the attendant. The control panel equipment may be varied to meet the different service requirements. Space is available on a shelf on the inside for a rectifier or an apparatus box where this additional equipment is necessary.

A typical circuit arrangement for a station connected to a *TWX* switchboard is shown in figure 10. The station is equipped with a switch which, when operated, applies power to the motor of the teletypewriter, and also closes the loop so that a relay in the central office is energized. This relay lights the answering lamps associated with the subscriber's multiple in the face of the switchboard. An operator answers by plugging the answering plug of a cord circuit into the jack. This action by the operator connects the station line to the cord circuit, and in addition energizes another winding of the relay previously energized when the subscriber called. This relay, being differentially wound, is then released and the answering lamps are extinguished.

In addition to calling the central office the subscriber must be able to recall the operator in case new services are required during the progress of the communication. This is accomplished by the subscriber simply turning the power switch off and then on again, which causes certain relays in the cord circuit to operate and the cord lamp to flash intermittently, indicating to the operator that her services are required. The subscriber must also be able to indicate to the operator when a disconnection has

Fig. 7. Sectional view of number 3A teletypewriter switchboard



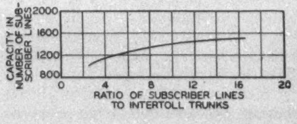

CAPACITY IN NUMBER OF SUBSCRIBER LINES
2000
1600
1200
800
0
4
8
12
16
20
RATIO OF SUBSCRIBER LINES TO INTERTOLL TRUNKS

Fig. 8. Curve showing variation of subscriber line capacity for number 3A teletypewriter switchboard

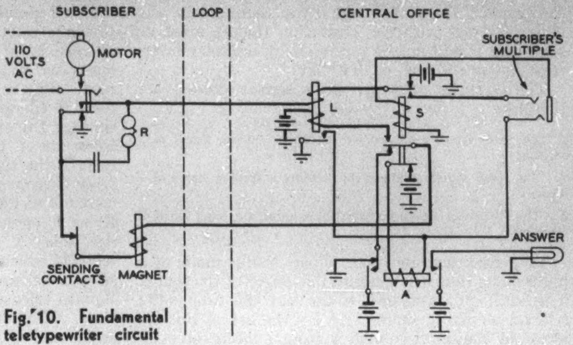


Fig. 10. Fundamental teletypewriter circuit

been made. This is accomplished by the subscriber turning off the power switch, causing the motor of the teletypewriter to stop and a lamp in the cord circuit to light.

The operator must also be able to signal the subscriber that a call is being completed to him. To provide this signal the station is equipped with a standard telephone type ringer which is energized, when the station is in the idle condition, by 20 cycle alternating current which flows over one side of the loop when the operator depresses a ringing key in the cord.

The teletypewriter lends itself admirably to the function of leaving messages on the subscriber's machine when no one is in attendance. When such service, known as unattended service, is desired, the station is similar to that already described, but additional equipment is provided for starting the motor from the switchboard. An attempt is made to complete the call on an attended basis as outlined above and, if the called subscriber does not answer, the operator asks the calling subscriber if he wishes to leave his message. If he does, she presses a key in the cord circuit, which starts the motor at the absent subscriber's teletypewriter. The operator then instructs the calling subscriber to proceed with the communication.

Long Subscriber Lines. The subscriber stations just discussed are connected to the central office by 2 wires, known as a loop, the maximum distance between station and switchboard for loop connections being approximately 38 miles. A network is placed in the loops where the mileage makes its use necessary to improve the transmission efficiency.

Fig. 9. Typical teletypewriter subscriber equipment for attended service

It is necessary in some instances to connect subscribers situated at greater distances from the switchboard, perhaps as much as 200 or 250 miles. Two methods are available for accomplishing this: the d-c method using telegraph facilities and the carrier method using telephone facilities.

With the d-c method a standard telegraph repeater is used at the central office, and a simplified repeater is placed on the subscriber's premises. These repeaters, with suitable signaling apparatus, provide a high grade of transmission and also the same type of supervisory signals as would obtain on the shorter loop connection.

The carrier method is used to a limited extent in the few instances where telegraph facilities are not available. With this method both the central office and the station are equipped with carrier apparatus and the regular telephone facilities are used. When the subscriber operates the power switch of the station, an answering lamp is lighted before the operator of the local telephone switchboard. The local operator, knowing by the multiple marking that this is a teletypewriter station, immediately connects through to the *TWX* switchboard over the regular toll telephone facilities. When the *TWX* switchboard is reached the call is handled in the same manner as a regular d-c telegraph connection. All the signaling facilities available for the other subscriber stations are also available here. Completion to the subscriber is also made by the *TWX* operator over the regular toll telephone facilities, and the local telephone operator at the switchboard to which the subscriber is connected rings the subscriber.

Intertoll Trunk Supervision. To provide intertoll trunk supervision in the *TWX* network, it was necessary to select types of signals different from those occurring during the normal transmission period of the teletypewriter; that is, the code and "break" signals.

Three types of supervisory signals are required to be sent over the intertoll trunk. These are (1) the call signal, (2) the recall signal, and (3) the disconnect signal. There is a fundamental difference, however, between the call signal and the others, in that it is applied to the trunk only when the stations are not connected. When the stations are connected, the apparatus for receiving the call is removed from the trunk. The calling signal can therefore be any type of signal with the limitation that it must be such that it will not be produced by ordinary interruptions on the line, or line "hits."

The 3 types of supervisory signals chosen are therefore:

1. The call signal, produced by sending a spacing signal of 2 seconds.
2. The recall signal, produced by sending a spacing signal of 7 seconds.
3. The disconnect signal, produced by sending a spacing signal of 10 seconds.

To permit sending these signals, use is made of a mechanism that will measure the length of the signal. The basic apparatus used to measure this time is the selector shown in figure 11. By the use of this selector in conjunction with a ground interrupted 60 times per minute, it is possible to obtain a means of measuring a line "open" within a sufficient degree of accuracy.

A typical method of sending and receiving the timed spacing signals or "opens" is shown in figure 12. The method of sending is shown at *A*, and the method of receiving at *B*. To send a recall signal, the operator at *A* presses the toll signal key momentarily, leaving the cord up, the sleeve relay therefore remaining operated. The closure of the toll signal key operates relay *A*. Relay *A*, operated, opens the loop circuit at both ends of the trunk, releasing relays *B* and *C*. Relay *B*, released, closes a circuit which causes the selector to step at the rate of 60 steps a minute. The release of relay *C* causes relay *D* to release and provide a circuit for the selector at *B* to step at the same rate. When the selector at *A* reaches the first point it locks relay *A* and both selectors continue to step until the selector at *A* reaches the seventh point, when the locking circuit of relay *A* opens and that relay releases, closing the circuit and reoperating relays *B*, *C*, and *D*. The reoperation of relay *B* energizes the release magnet of the selector through the off normal contacts which causes the selector at *A* to release. At *B*, when the selector reaches the sixth point, relay *K* operates and, when relay *C* reoperates, ground is connected through the contacts of relays *K*, *L*, and *M* to operate relay *N*. Relay *N* connects ground to the cord lamp, lighting it. Relay *N*, when operated, also connects ground to relay *M* which locks under control of contact *P*. The selector releases and after a time relay *K*, which is slow to release, also releases causing relay *N* to release. The release of *N* connects ground interrupted at the rate of 60 times per minute to the lamp which flashes until contact *P* is opened by the typing key, releasing relay *M*.

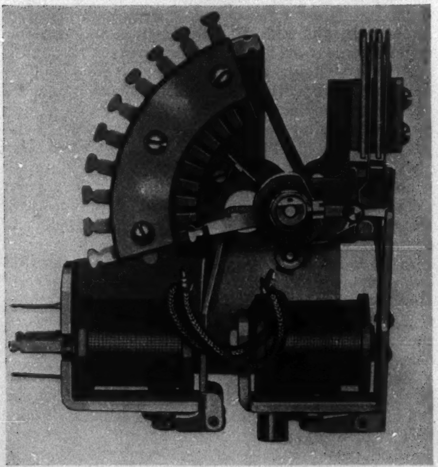


Fig. 11. Selector used for timing supervisory signals

To send a disconnect signal the same operations take place at *A* except that, immediately after the cord key is operated, the cord is pulled down, releasing the sleeve relay, and causing the selector at both ends to continue to the tenth point. At *B* when the selector reaches the tenth point relay *L* operates and, when relay *C* reoperates, ground is applied to operate relays *M* and *N* which hold a steady ground on the cord lamp until the cord is pulled down.

These signals appear at all offices in a built-up connection. The frequency of the machines supplying the 60 interruptions per minute is accurate to within plus or minus 5 per cent, and the multiple connections on the receiving selector bank take up any inequalities that may exist in the speed of the machines in 2 different offices.

That section of the receiving selector between terminals 1 to 5 inclusive is used for the call signal which is actuated manually by the originating operator.

Cord Circuits. In order to provide each operator with sufficient traffic for operating efficiency, especially in the smaller offices and during light load periods, the cord circuits in the *TWX* switchboards are made universal, that is, adapted to handling all types of calls. This universal feature is obtained by equipping them with a simple type of repeater. By means of this repeater it is possible to provide for the maximum length of station loop and at the same time establish the following connections:

1. Subscriber line to subscriber line, known as a local to local connection.
2. Intertoll trunk to subscriber line, or *vice versa*, known as a toll to local connection, or local to toll connection.
3. Intertoll trunk to intertoll trunk, known as a through connection.

In a local to local connection the 2 loops could not be connected together directly unless the repeater were provided in the cord circuit for 2 reasons: first, each loop may be maximum in length so that the 2 loops in tandem would result in the operating current being halved; and second, each loop is normally terminated on the negative side of the telegraph battery. Because it is essential, in *TWX* service, to make interconnections without requiring adjust-

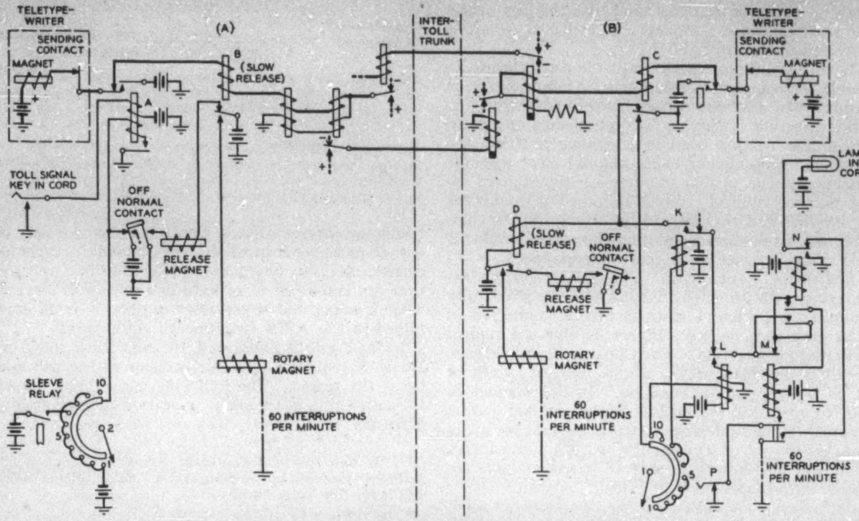

TELETYPE-WRITER
SENDING CONTACT
MAGNET
(A)
B
(SLOW RELEASE)
A
INTER-TOLL TRUNK
(B)
C
TELETYPE-WRITER
SENDING CONTACT
MAGNET
LAMP IN CORD
TOLL SIGNAL KEY IN CORD
OFF NORMAL CONTACT
RELEASE MAGNET
D
(SLOW RELEASE)
OFF NORMAL CONTACT
RELEASE MAGNET
K
N
L
M
ROTARY MAGNET
ROTARY MAGNET
SLEEVE RELAY
10
5
2
1
60 INTERRUPTIONS PER MINUTE
60 INTERRUPTIONS PER MINUTE
10
1
5
1
P
60 INTERRUPTIONS PER MINUTE

Fig. 12. Fundamental intertoll trunk signaling circuit

ments, all loops are padded or "built out" to the same value as the resistance of a maximum loop and each side of the cord circuit repeater is arranged to operate with each loop.

With the provision of the repeater in the cord circuit to permit interconnecting 2 subscriber lines the same cord may be used for toll to local and toll to toll connections because the loop circuits of the intertoll trunk repeaters are all terminated on the negative side of the telegraph battery and the loop resistance of each is built out to equal that of the longest station loop.

A very simplified form of the essential elements of a *TWX* cord circuit is shown in figure 13. The cord circuit basically consists of a repeater of the type before mentioned, a key known as the typing key, by means of which the operator may cut her teletypewriter in and out of the circuit for monitoring purposes, and facilities for receiving the recall and disconnect signals both from the subscriber lines and the intertoll trunks.

The method of receiving these recall and disconnect signals was explained in the section on intertoll trunk supervision, and the method used to receive those from the subscriber was pointed out in the subscriber circuit description. Many other items are included in the cord circuit by means of which the operator may expedite the setting up and removing of connections. Among these items is the busy test. When an operator is about to complete a call to a station it is necessary that she know that the station is free to receive the call. To ascertain this a means is provided so that she may make a tip busy test on the sleeve of the jack associated with that subscriber line and, if the station is busy, a position light will be lit. If no light is received the operator will plug into the jack and complete the connection.

Multiple appearances of the jacks and lamps associated with subscriber lines and intertoll trunks are provided so that a number of operators may be available to answer a call from a station or an intertoll trunk. If more than one operator answers it is necessary that

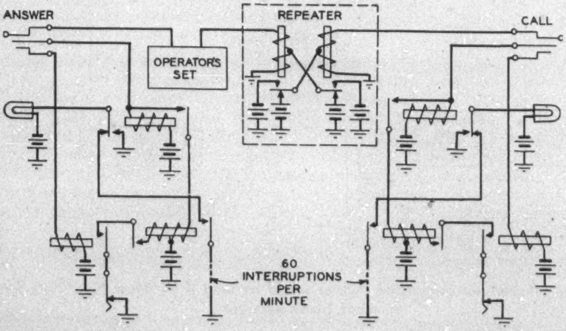

ANSWER
REPEATER
CALL
OPERATOR'S SET
60 INTERRUPTIONS PER MINUTE

Fig. 13. Typical cord circuit

they be aware of that fact, and that the first operator shall take and complete the call. A circuit is provided to indicate this.

Facilities are provided to split the cord, that is, to enable the operator to communicate in one direction without the communication being recorded in the other direction. Ringing is accomplished in a manner similar to that used in telephone practice, the number 1 switchboard using manual start machine ringing and the smaller number 3*A* switchboard using manual ringing. While the cord is connected to one line and the operator is attempting to complete the connection to another line, the first line is held closed in order not to mar transmission.

Conference Connections. The teletypewriter exchange system provides a means whereby practically unlimited numbers of stations can be connected in conference connections. Figure 14 shows a typical conference connection. Each link in the conference circuit is provided with a simple repeater, each of which is equipped for breaking. In this manner to and fro operation by the half-duplex method can be attained. The conference repeater circuits are made up in groups of 5 or 10, each of which is equipped with a multiple appearance so that all operators have access to the repeaters.

Regenerative Repeaters. It is necessary in some long circuits to improve transmission by inserting a regenerative repeater in the circuit. To make this possible and easily performed by any operator, regenerative repeaters are provided with a complete jack multiple appearing before all operators. Both ends of the repeater are available in this multiple and the repeater may be inserted where the transmission equivalent of the circuit involved makes it necessary.

TYPICAL BUILT-UP CONNECTION

In order to provide *TWX* service on a nationwide basis certain of the connections require one or more intermediate switchboards so that one or more through operators may be involved. As an illustration of this figure 15 shows a connection established between a calling station in New York and a called station in San Francisco with a through switch at Chicago, a method used when all direct trunks are busy. This figure shows the manner in which the *TWX* equipment has been arranged to operate in conjunction with the telegraph line facilities. The station loop is a pair of wires such as those used for telephone service. Each intertoll trunk consists of one or more sections of the same standard types of carrier, metallic, or grounded telegraph line systems that are employed in private line telegraph service. The signaling and supervisory apparatus is all contained in the *TWX* switchboard equipments.

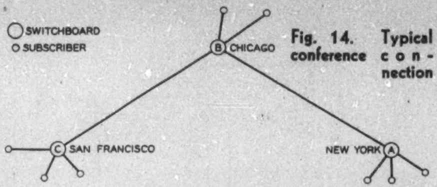

SWITCHBOARD
SUBSCRIBER
B CHICAGO
C SAN FRANCISCO
NEW YORK A

Fig. 14. Typical conference connection

In the example illustrated, the New York operator, being the outward operator, supervises the call and times the ticket. The following traffic table shows the important steps taken in setting up and taking down this connection:

(1). **The New York subscriber calls:** Subscriber closes loop and starts teletypewriter by operating switch. Subscriber line lamps light in the New York switchboard.

(2). **The New York operator answers with the cord typing key (similar in function to the talking key in the telephone cord circuit) operated:** The line lamps are extinguished. The operator and subscriber communicate.

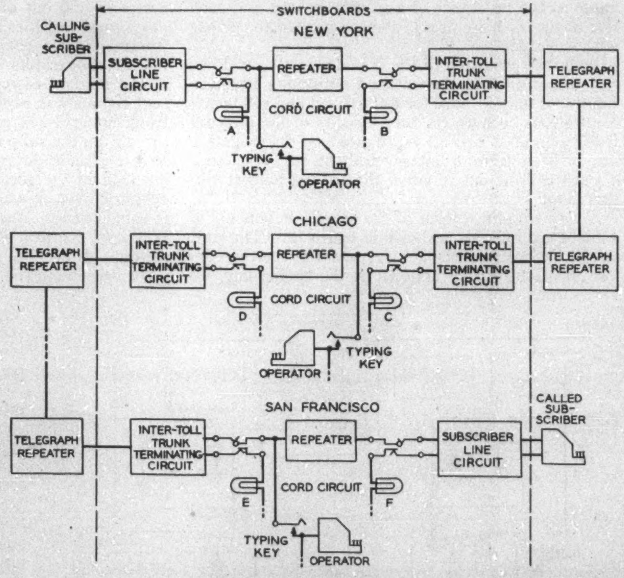

SWITCHBOARDS
CALLING SUB-SCRIBER
NEW YORK
SUBSCRIBER LINE CIRCUIT
REPEATER
INTER-TOLL TRUNK TERMINATING CIRCUIT
TELEGRAPH REPEATER
CORD CIRCUIT
A
B
TYPING KEY
OPERATOR
CHICAGO
TELEGRAPH REPEATER
INTER-TOLL TRUNK TERMINATING CIRCUIT
REPEATER
INTER-TOLL TRUNK TERMINATING CIRCUIT
TELEGRAPH REPEATER
CORD CIRCUIT
D
C
TYPING KEY
OPERATOR
SAN FRANCISCO
CALLED SUB-SCRIBER
TELEGRAPH REPEATER
INTER-TOLL TRUNK TERMINATING CIRCUIT
REPEATER
SUBSCRIBER LINE CIRCUIT
CORD CIRCUIT
E
F
TYPING KEY
OPERATOR

Fig. 15. A built-up connection such as would be used if all direct New York-San Francisco trunks were busy

(3). The New York operator connects to an idle trunk in the New York-Chicago multiple: Plugs the completing end of the cord into the trunk jack and operates the cord ringing key for 2 seconds. The trunk multiple lamps at Chicago light.

(4). The Chicago operator answers: Plugs the answering end of a cord into the trunk jack with the cord typing key operated. The trunk lamps are extinguished. The Chicago operator communicates with the New York operator.

(5). The Chicago operator completes to an idle trunk in the Chicago-San Francisco multiple: Plugs the completing end of the cord into an idle trunk jack and operates the cord ringing key for 2 seconds. Releases typing key. The trunk multiple lamps at San Francisco light.

(6). The San Francisco operator answers: Plugs the answering end of a cord into the trunk jack with the cord typing key operated. The trunk lamps are extinguished. The San Francisco operator communicates with the New York operator.

(7). The San Francisco operator completes the connection to the called subscriber line: After making a tip busy test with completing cord to insure that the called station is idle the San Francisco operator plugs into the jack and operates the ringing key in that cord. The ringer in the San Francisco station is operated.

(8). The called subscriber answers: The answer is received on the operators' teletypewriters at the San Francisco and New York switchboards and at the New York subscriber station. The San Francisco and New York operators release the cord typing keys leaving the communication between the subscribers. The New York operator starts timing the ticket.

(9). The calling and called subscribers disconnect: Lamps *A* and *F* light. The New York operator completes the timing of the ticket.

(10). The outward (New York) operator sends the disconnect signal: Operates cord key momentarily and pulls down both cords. After 10 seconds lamps *C*, *D*, and *E* light.

(11). The inward (San Francisco) and through (Chicago) operators disconnect: Upon noting the disconnect lamp signals both operators pull down both cords.

If during the progress of the call the subscriber desires to regain the attention of the operator, a recall signal is sent. The procedure in this case is as follows:

(12). The calling (or called) subscriber recalls: Operates power switch at the station. Cord lamp *A* (or *F*) flashes.

(13). The operator answers the recall: Operates cord typing key connecting her teletypewriter to the circuit. The flashing cord lamp is extinguished.

(14). The outward (New York) operator recalls the inward and through operator at Chicago: Operates recall key in cord. After 7 seconds lamps *B*, *C*, *D*, and *E* flash. The outward operator releases the typing key momentarily to extinguish lamp.

(15). The inward and through (San Francisco and Chicago) operators challenge: Operate cord typing keys which extinguish the flashing lamps, and then challenge by typing.

This paper has outlined the technique of teletypewriter switchboard operation as it stands today. Although the designs as here outlined have given satisfactory service within due limits of economy, the expansion of the system and experience in its operation will undoubtedly lead to changes in the design of both the equipment and circuits and to changes in the methods of operation to increase the efficiency and improve the quality of the service.

REFERENCE

1. A TRANSMISSION SYSTEM FOR TELETYPEWRITER EXCHANGE SERVICE, R. E. Pierce and E. W. Bemis. ELECTRICAL ENGINEERING, v. 55, Sept. 1936, p. 961–70.

A Disturbance Duration Recorder

The recorder described in this paper was developed for measuring and recording the duration of subnormal voltages that result from system faults. The device is simple and inexpensive in operation, and records system disturbances as they occur.

By
C. H. FRIER
MEMBER A.I.E.E.

Oklahoma Gas and Electric Co.,
Oklahoma City

APPLICATION of protective relays to an electric power system involves 2 vital factors: first, that only the breakers required for clearing a fault will be tripped open and all other breakers remain closed; second, that the required breakers operate as quickly as possible and thereby isolate the fault from the remainder of the system. The first is obviously essential, while the second not only determines the quality of electric service rendered, but also affects the stability of an interconnected system immediately after the fault occurs. Thus the quality of service as well as the ability of generating plants to continue in synchronous operation depends largely upon the length of time the fault is allowed to remain on the system. The length of time utilized in isolating a fault is therefore a matter of great importance to satisfactory operation of a large power system.

Because the protective relays associated with each breaker constitute such an important factor in the isolation of a fault, it is a customary practice to make occasional tests of the tripping time of each relay as well as of the opening time of the breaker. The sum of these intervals, however, does not give the total time required for the isolation of a fault on an interconnected system, simply because there are 2 or more breakers involved, all of which must operate in order to isolate the fault. In some instances the system characteristics are such that one breaker does not carry an appreciable fault current until after another breaker has opened; the total time then consumed in isolating the fault is the sum of the separate intervals utilized by all breakers and their relay equipment. Also when time-delay induction-type relays are used, where the relay settings of the various sections are cascaded and the tripping time of each

---

A paper recommended for publication by the A.I.E.E. committee on protective devices, and scheduled for discussion at the A.I.E.E. South West District meeting, Dallas, Texas, October 26–28, 1936. Manuscript submitted July 15, 1936; released for publication August 14, 1936.

The author desires to acknowledge the aid of his co-workers, A. W. Walton, P. O. Bobo, and J. D. Browder, in the construction of the model and the preparation of this paper.

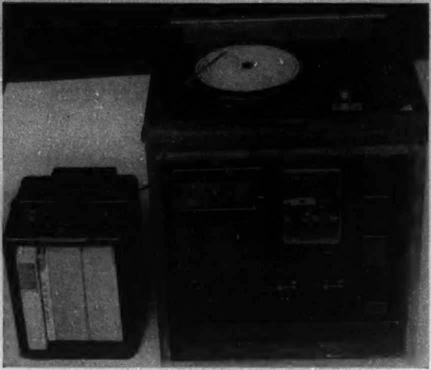


Fig. 1. Disturbance duration recorder

relay is inherently a function of the fault current, relay tripping times as determined by occasional tests are not absolutely indicative of how the relays will operate under actual fault conditions. This fact is obvious upon considering the different types of faults, together with variable generating capacities. The general practice of testing relays and oil circuit breaker mechanisms is not censured, but its limitations with reference to predicting actual operations under fault conditions are recognized.

For several years the relay department of the Oklahoma Gas and Electric Company has endeavored to obtain a practical device for measuring the actual durations of voltage disturbances or fault conditions. An automatic oscillograph has been used for this purpose and some valuable data obtained therefrom, but the equipment is very expensive, delicate, and requires considerable expert attention. Its records are available only after the films have been developed; and when several disturbances occur in quick succession it is not possible to obtain a record of all of them. Furthermore, it is often difficult to identify a record with respect to the corresponding disturbance.

The disturbance duration recorder, as developed by the company, has been in successful use since February 1, 1936. It has been very effective not only in locating faulty relays and breakers, but also in revealing that the relaying of certain sections of the transmission system could be improved greatly without making expensive alterations on the original equipment. It has proved definitely that the application of instantaneous overcurrent relays,[1] and consequent decrease in time settings of the overcurrent induction relays, is practical and economically justified.

The duration recorder is connected to the system in continuous service at all times, and is located in the system dispatcher's office. It requires very little attention, and records the duration of all voltage dips of 4 volts or more.

Figure 1 is a front view of the device. On the top surface, accessible by raising the glass cover, is a circular chart attached to a metal turntable which revolves at a constant speed under a metal stylus. The chart is not in contact with the stylus, but revolves freely beneath it. Waxed paper demand-meter charts are used, and the record is made by an electric spark passing through the chart between stylus and turntable. The spark, upon puncturing the thin layer of carbon underneath the wax, leaves a black dotted line distinctly visible to the unaided eye. The circular length of this dotted line is a measure of the time interval, since one revolution corresponds to 2 seconds time.

Figure 2 shows the schematic arrangement of the various electrical and mechanical features entering into the operation of the device. The spark is produced by a vibrator type of ignition coil and battery, controlled from a contact-making voltmeter which is constantly energized from the local supply circuit. The stylus arm is supported by a vertical shaft which can be rotated by a notching relay, so that after a disturbance has occurred—as well as for each revolution of the chart during a long disturbance—the stylus is notched once toward the center of the chart, thereby preventing the dotted line from overlapping and thus giving a separate and distinct record for each disturbance. This is accomplished by the peculiar arrangement of the notching relay, together with a pair of contacts, *TC*, mounted under the turntable and momentarily closed once during each revolution. The notching relay, spark coil, and d-c recording voltmeter shown at the lower left in figure 1, are energized simultaneously. The purpose of the voltmeter is to record the time that each disturbance occurs.

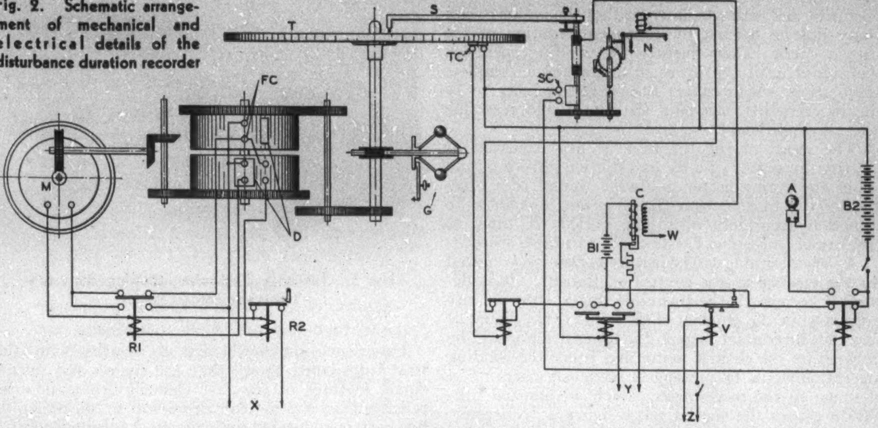
After the recorder has operated and normal voltage has been restored, the initiating circuit is opened by the contact-making voltmeter, the spark ceases, the stylus moves over to a new position, and the device is then ready for the next disturbance. Several disturbances may therefore be recorded on a single chart, as illustrated by the sample chart depicted in figure 3. The equipment is so arranged that when the entire chart has been used, an alarm sounds and the spark coil circuit is automatically opened. This latter action is controlled by a pair of contacts, *SC*, which are normally open, but are closed by the stylus shaft after the stylus is notched to the center of the chart, as indicated in figure 2. Batteries are used for operating the alarm, notching relay, and spark coil because dependence cannot be placed on the a-c power supply during system disturbances.

The mechanism which drives the turntable is shown in figure 4. It consists of a standard phonograph hand-wound spring motor, with gear train, governor, and turntable, to which is attached the necessary auxiliary apparatus, including a small electric motor for winding the springs and the stylus notching assembly shown on the side opposite to the electric motor. All of the various parts of this complete mechanism are co-ordinated electrically and mechanically in a manner that assures positive action, dependability, and minimum wear.

---

[1] USE OF INSTANTANEOUS OVERCURRENT RELAYS FOR DISTANCE RELAYING, C. H. Frier. ELECTRICAL ENGINEERING (A.I.E.E. TRANSACTIONS), v. 54, April 1935, p. 404–7.

Fig. 2. Schematic arrangement of mechanical and electrical details of the disturbance duration recorder



A—Alarm bell
B1—Battery, 6 volts
B2—Battery, 67.5 volts
C—Spark coil
D—Drum segments
FC—Finger contacts
G—Friction governor
M—Motor
N—Stylus notching assembly
R1—Operating relay
R2—Special relay
S—Stylus
SC—Contacts; close when stylus has traversed complete arc distance
T—Turntable
TC—Contacts; close once per revolution of turntable
V—Contact-making voltmeter
W—Connection to metallic frame of turntable
X—110 volts alternating current for motor
Y—Connection to recording voltmeter
Z—110 volts alternating current for contact-making voltmeter

Stopping the turntable for inspection and labeling of records, or renewing the chart, is accomplished by manipulating a small lever which constitutes a regular feature of the mechanism. Power for driving the turntable is supplied directly from the spring motor, which has 2 units joined in series to the gear train. Each unit consists of a heavy clock spring enclosed by a housing drum to which a driving gear is rigidly attached. Energy is expended from the gear of the upper spring, figure 2, and replenished at the gear of the lower spring by the small a-c motor which operates at definite intervals. The upper spring drum and gear rotate constantly in the clockwise direction, and the lower drum also rotates in the same direction while the spring motor is being wound. The spring motor is always wound to a practically constant tension because for each revolution of the upper drum and driving gear, the lower winding gear and drum are rotated one revolution by the electric motor. This unique winding operation is obtained by a relay acting in conjunction with segments mounted on the spring housing drums and associated with stationary contact fingers as shown in the photograph, figure 5, as well as in the schematic arrangement, figure 2.

Referring to the latter, the 2 drums with their respective segments and finger contacts are shown relatively when the lower drum is stationary and the upper drum is rotating clockwise, as indicated by the arrow. As the upper drum continues to rotate, its segment bridges the contacts and thus closes the motor circuit. The lower drum is then rotated in the same direction as the upper, but at a much faster speed, so that the lower drum segment disengages its contacts before the motor circuit is opened by the segment of the upper drum. Upon disengagement of the lower drum contacts and segment, the operating relay is de-energized, thus breaking its upper contacts and closing its lower contacts. This operation by-passes the upper drum

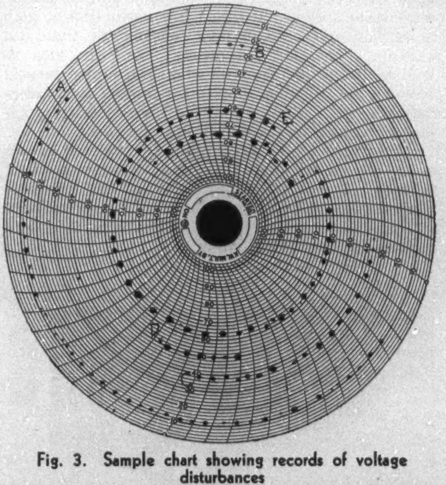


Fig. 3. Sample chart showing records of voltage disturbances

A, B, C, D, and *E* indicate starts of first, second, third, fourth, and fifth disturbances, respectively; notching action of stylus is shown during the fifth disturbance. Radial lines indicate time of 1.875 cycles segment and contacts, in order that the motor circuit may not be opened by continued rotation of the upper drum. Consequently the winding operation continues until the lower drum makes a complete revolution, which causes the operating relay to be again energized, stopping the motor and restoring circuit conditions to normal.

The speed of the turntable is held constant at 30 rpm by means of a fly ball friction governor, and since the spring motor is always wound to a practically constant tension the governor is enabled to function accurately over long periods of time, as evidenced by frequent tests of the turntable speed.

A very desirable safety feature is also incorporated in the electric motor control equipment. It is desirable because, if the turntable should stop for any reason while the segment of the upper drum (figure 2) is under its contact fingers, the lower drum would be rotated by the electric motor and hence the winding operation would be prolonged, obviously resulting in damage to the mechanism. Such an unusual condition causes the special relay, figure 2, to be energized immediately by means of the second pair of contact fingers associated with the lower drum. This relay latches its contacts open, thereby disconnecting the a-c power supply and preventing the spring motor from being overwound or causing damage to any part of the mechanism.

The duration recorder was originally constructed as an experiment, with the hope of ascertaining whether or not the general idea was practical. Consideration was first given to a turntable driven by a d-c motor supplied from a battery and equipped with a speed regulator. It was soon realized, however, that a special gear train would be required, that some difficulty might be encountered in maintaining a constant speed, and that the construction of such a mechanism would involve considerable time and expense. Therefore, in order to test the idea as well as to expedite the production of an experimental model, the phonograph spring-motor mechanism was selected. To it was fitted the necessary auxiliary apparatus as previously described.

Three primary elements of the completed device were considered and have been closely studied, namely, (1) the mechanism driving the turntable continuously at a uniform speed; (2) the sensitivity of response to voltage dips; and (3) the chart and method of drawing the curve.

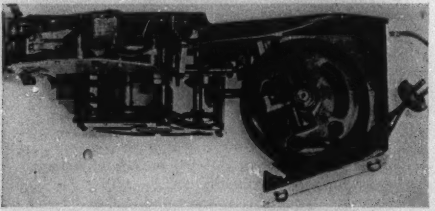


Fig. 4. Turntable mechanism, showing stylus notching assembly at left

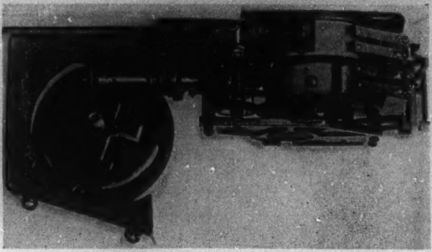


Fig. 5. Turntable mechanism, showing drum segments and contact fingers

Experience during almost 6 months with the model described shows that the design and operational features of the first element are sound and reliable from a practical viewpoint, as no difficulty has been encountered with the mechanism or control equipment. No appreciable wear of the bearings or gears has resulted, because these moving parts are kept well oiled and greased. The 2 motor springs, which are usually the first items to fail, have continued to operate as originally installed. When necessary, either or both may be replaced at a very nominal expense.

The second element concerns only the inherent time lag of the contact-making voltmeter and spark coil, since their operations begin after the system voltage drops to a value fixed by the adjustments of the contact-making voltmeter. Careful tests made for determining this time lag show that it lies between 1 and 3 cycles, and depends largely upon how much the normal voltage must drop. This low value is of no great disadvantage, although some consideration has been given to its reduction by substituting an electronic control for the contact-making voltmeter.

The third element, the chart, is not satisfactory in every respect. The electric spark method of drawing the curve originally was selected in order to avoid the troubles with conventional ink pens. Common paper charts were first used, but the small holes made by the sparks were hard to identify. It was soon found that waxed-paper demand-meter charts were better suited, as the holes are plainly outlined by the carbon contained in this type of chart. These charts are expensive and not of sufficient size to cover the entire turntable. Consequently consideration is being given to the development of a larger and less expensive chart, one designed expressly for the purpose, and consisting preferably of ordinary thin paper impregnated with a suitable chemical that will discolor the paper around the holes as a result of the heat of the electric sparks.

In general the device is satisfactory. It does not, of course, compare with an oscillograph. However, it provides a simple and effective means of timing voltage disturbances with a fair degree of accuracy, and is most certainly useful in keeping a constant check on system relay operations.

The Control Gap for Lightning Protection

The use of air gaps between various forms of electrodes to discharge high surge voltages and thus protect expensive apparatus from damage is general, but such gaps vary in time delay and polarity characteristics and are difficult to co-ordinate with the insulation to be protected. By controlling the electrostatic field, the gap described in this paper provides a wide range of time and polarity characteristics that enables insulation co-ordination to be more readily effected.

By
RALPH HIGGINS
ASSOCIATE AIEE
H. L. RORDEN
ASSOCIATE AIEE

Both of the Ohio Brass Co., Barberton, Ohio

PROTECTION of terminal apparatus against overvoltages has been found necessary since the beginning of the art of high voltage transmission. One of the commonest forms of such protection has been a gap in air, and this is still depended upon in large measures today. Unfortunately, the volt-time flashover characteristic of such a gap does not ordinarily conform to the corresponding characteristic of the insulation to be protected. However, by controlling the dielectric field about such a gap the so-called time lag characteristics can be varied at will and made to conform to almost any desired curve. Time lag curves of the gap for both polarities can be made approximately alike. In view of the importance assigned to insulation co-ordination, it is believed that this control type of gap will find a definite application. The following possibilities are offered:

1. For limiting-gap protection of transformers and other insulation, the volt-time and polarity characteristics can be controlled over a wide range.
2. The gap can be given an almost flat volt-time flashover curve with values nearly equal for both polarities.
3. Increased protection with minimum service interruptions may be obtained by using control gaps as backup protection in conjunction with lightning arresters.
4. The control gap in conjunction with quick reclosing breakers may offer surge protection without service interruption.

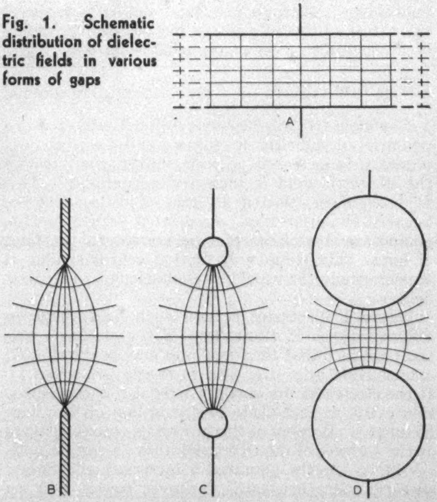
Surge Protection

Considerable interest has been shown during recent years in protection from high voltage surges. Much of the problem is not susceptible to a rational analysis and, therefore, most of what is known and has been analyzed rationally is based on assumptions, observations, and tests. This trial and error method is undoubtedly responsible for the lack of unified opinion on the subject, and accounts for the many forms of partial protection which are in general use. Some of these devices have, without question, prevented dielectric failures in expensive equipment. However, they are not infallible and occasional failures still seem to occur.

Means that afford some degree of protection and are recognized as a step in the right direction include lightning arresters, ground wires and counterpoises, limiting gaps, increased insulation, improved distribution of dielectric stress, and various combinations of the foregoing. There is little doubt that each of these has established its merit and plays a definite part in present practice.

The foremost object in providing protection against surge voltages is to prevent the dielectric failure of expensive equipment, such as transformer insulation. For complete protection, the protective device must function before any other connected equipment will flash over or fail at any voltage and current, must not change characteristics seriously under changing weather conditions, and must be capable of functioning under successive discharges. Prevention of outages, as well as protection of other equipment, is of major importance, but it is better to protect equipment and tolerate an interruption to service than to be forced to tolerate both the failure and outage. The operations of a protective device for the higher surge voltages would prob-

Fig. 1. Schematic distribution of dielectric fields in various forms of gaps



A paper recommended for publication by the AIEE committee on protective devices, and tentatively scheduled for discussion at the AIEE winter convention, New York, N. Y., January 25–29, 1936. Manuscript submitted March 12, 1936; released for publication July 2, 1936.

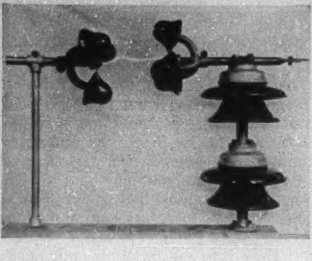


Fig. 2. Control gap for lower range of voltages

ably not be frequent and therefore the outages would be few. One such operation, however, would more than justify the installation.

Were it not for variations in time lags, insulation co-ordination would be simple. It would be necessary then only to proportion the strength of all insulation so that that which is less expensive and most easily replaceable would, in all instances, be weaker and thereby protect the more expensive. The complication arises because the most expensive equipment is the most vulnerable.

When subjected to surge voltages that are at or above the minimum required to produce failure, transformer major insulation will fail in a relatively short interval of time. That is, such insulation will break down within a few microseconds if it will fail at all. Flashover of bushings or supporting insulation may be delayed for considerably longer periods of time after the application of a voltage just sufficient to produce flashover. With voltages increasing beyond this minimum, although this time delay becomes increasingly shorter, there is a considerable voltage increase before such delay approaches the short times associated with the failure of major insulation. Although investigations have disclosed the nature of the difficulty, a method of overcoming it satisfactorily has been most difficult to find.

DIELECTRIC FIELDS

Any dielectric will flash over or fail if subjected to a potential of sufficient magnitude and duration. As potential is increased up to flashover, the stress of the dielectric field is increased accordingly. This field might be plotted as lines of dielectric force between the electrodes. Associated with it are the equipotential surfaces plotted normal to the lines of force. The completely plotted field is similar in appearance to the usual representation of a magnetic field.

Figure 1 illustrates several such fields between different types of electrodes. If the electrode surfaces are such that the force lines may be distributed over a wide area, the field is nearly uniform (*A*). If the electrodes are small or irregular, a concentration exists so that there is a crowding of flux lines (*B* and *C*). Because of this crowding, corona appears at the surfaces of the electrodes above a certain voltage limit. As the potential is increased, the corona streamers lengthen until flashover occurs. In an ideally uniform field, there would be no crowding of flux and complete flashover would occur with practically no time delay at the instant the corona point was reached. In the sphere gap of small spacing (*D*), the dielectric field at any voltage below flashover is substantially uniform.

The point or rod gap (*B*) and the sphere gap (*D*) are practical approaches to opposite extremes of concentrated and uniform dielectric fields. If a surge voltage of a magnitude just sufficient to flash over a sphere gap is applied, the flashover occurs at almost the instant the potential reaches its crest. Applied to a rod gap, the potential remains for a longer period of time before flashover occurs. The crest of such applied voltage waves is known as the minimum flashover voltage. Higher crest values which reduce the "time lag" are known as overvoltages.

If a sphere gap and a rod gap are adjusted to have the same minimum flashover voltage, and are then simultaneously subjected to an overvoltage, the sphere gap only will flash over. If the sphere gap were not present, the rod gap would flash over after the time delay necessary to form the corona streamers. Spheres are said to have a flat volt-time characteristic. This is a misnomer, for the curve ends abruptly at its minimum flashover voltage. Rod gaps have a sloping characteristic (see figure 9).

This brief analysis might be applied to flashovers in general. Where the dielectric field is substantially uniform or where a breakdown voltage is not dependent upon the formation of corona streamers, there is little or no time lag. Where corona must contribute to producing flashovers, there is a definite time delay.

Flashover potentials of both polarities (usually taken with respect to ground) are affected by the shapes of the electrodes. The minimum impulse flashover of a given rod gap requires a negative potential higher than the positive potential. The reverse is true of flashovers of sphere gaps at their wider spacings. The difference is less pronounced in

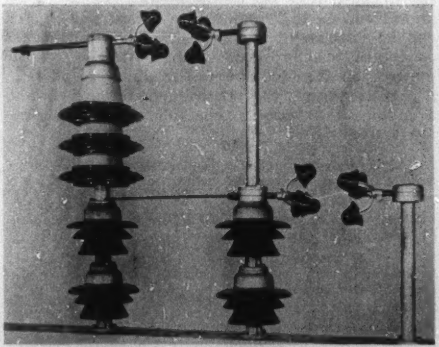


Fig. 3. Arrangement of 2 gaps in series for use on higher voltages

sphere gaps; in fact, at the lower spacings the potentials are equal. (Incidentally, the breakdown of solid insulation on both polarities is said to be very similar to the breakdown of sphere gaps.) In point to plane gaps, if the point is grounded, the positive polarity flashover voltage is higher than the negative. The reverse is true if the plane is grounded. It is apparent that a means is hereby offered for controlling flashover voltages by control of the dielectric field. Thus it is possible to keep flashover potentials of both polarities almost equal at a given spacing by proper arrangement and shape of electrodes.

PRINCIPLE OF CONTROL GAPS

One form of the protective gap described here is illustrated in figure 2. The object of this gap is to protect major insulation without encountering the objectionable features which limit the use of sphere gaps, rod gaps, ring gaps, and the like. This device is so designed that a relatively uniform dielectric field is obtained although the arcing electrodes are small. The advantage of short time lags (relatively flat volt-time characteristics) is hereby obtained without the disadvantage of low flashover voltages when the parts are wet. These electrodes might be said to function like spheres under surge conditions and like points at power frequencies. The distributed dielectric field is obtained by means of control shields surrounding the arcing terminals. These shields are so placed that they increase the effective electrode areas, and are insulated to prevent breakdown at other than the arcing terminals.

In agreement with the general theory, tests show that the range of gap spacings for short time characteristics is limited. Thus, for flashovers of higher voltage, if the same performance is to be obtained in a single gap, the size of the control field would be excessive. This objection is overcome by resorting to a multigap design. For the protection of systems rated up to 100 kv the desired characteristics are obtainable in a single gap. Above 100 kv the same performance is obtained by placing 2 of the lower voltage gaps in series, as is illustrated in figure 3. The inherent difficulties associated with multigaps must be met. In this form of gap capacitance is introduced between the arcing terminals so that regardless of the applied potential, each of the series gaps assumes approximately half of the total applied voltage. These capacitances must be large enough to maintain electrical stability in all weather.

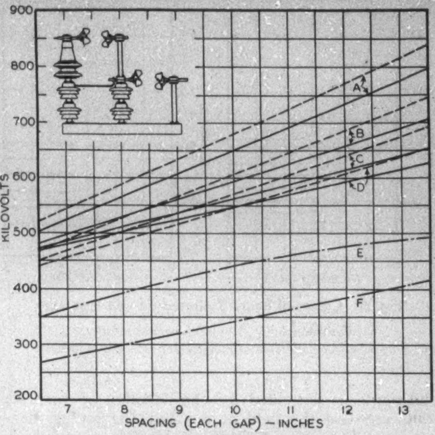


Fig. 5. Impulse flashover characteristics of control gap for use in 115–138 kv range

A—1½ microsecond flashover
B—2 microsecond flashover
C—2½ microsecond flashover
D—Minimum flashover
E—60 cycle crest, dry
F—60 cycle crest, wet

Solid curves positive polarity; dashed curves negative polarity

Test wave 1½ x 40 microseconds; times given are total from zero to flashover

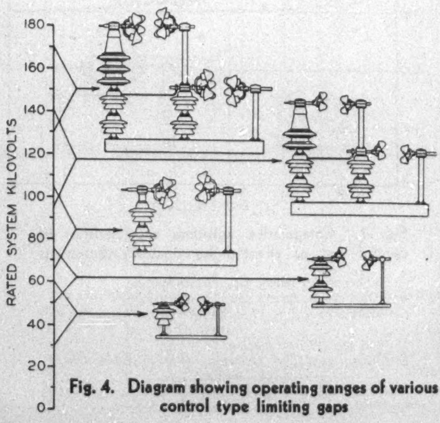


Fig. 4. Diagram showing operating ranges of various control type limiting gaps

RANGE OF CONTROL GAPS

A complete group of these gaps is available for system voltages ranging from 30 to 170 kv. The different forms and their respective operating ranges are shown in figure 4.

The 2 lower voltage gaps have the same type of insulated controls, differing only in the supporting insulation. For voltages immediately above this range, an additional group of insulated arms is provided to increase the effective diameter of the dielectric field and permit a corresponding increase in the gap spacing. The multigap type for system voltages immediately above 100 kv consists of 2 gaps of the lowest voltage type in series. If the spacing of each of these gaps is maintained within the satisfactory range of a single gap, this control gap has a performance characteristic very similar to that of the single gap. This presupposes that the 2 series gaps are so adjusted that each receives its due proportion of the total voltage applied. As in the lower voltage gaps, the operating limit of the

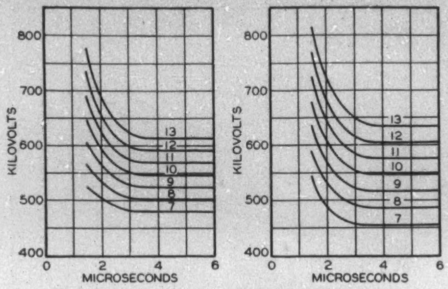


Fig. 6. Curves of figure 5 plotted on volt-time axes

Positive polarity Negative polarity

Numbers on curves indicate spacing of each gap in inches

multigaps is extended by the addition of controls that increase the field area about the arcing electrodes. The present limit of this gap may be extended by increasing the supporting insulation.

Performance curves for the control gap shown in figure 3, so adjusted as to give relatively flat volt-time characteristics, are given in figures 5 and 6. These curves, involving 3 variables, are given in 2 forms. Flashover voltages are plotted against gap spacing in figure 5. These curves are convenient for adjusting the spacing to a desired voltage. However, these data are more commonly plotted on a volt-time basis as in figure 6. In addition to obtaining short time performance, the gap is adjusted to obtain flashovers at nearly equal voltages on both polarities over the entire range of gap spacings. It is not possible to obtain exactly equal flashover voltages with both polarities over this range without readjustment of the controls. It is possible, as these curves illustrate, to obtain a balance at one spacing and maintain a relatively small difference throughout the entire range.

The 60 cycle crest flashover voltages are given also in figure 5. If the minimum flashover level of the control gap is maintained within a reasonable margin below the recommended transformer test level,[1] the 60 cycle wet flashover voltage is 3.5 or more times the line to neutral voltage. Outages from switching surges should therefore be rare.

CONTROL ADJUSTMENTS

Control of both flashover voltage and time lag is possible with these gaps, as has been described previously[2] and as is further illustrated in figure 7. At 17 inch spacing and with the control shields set back from the arcing electrodes (X and Y dimensions 11 inches each) the control gap curve follows very closely that of the rod gap. If these controls are brought nearer the arcing electrodes, thus affording greater shielding (X and Y dimensions $6^1/_2$ and $8^1/_2$ inches, respectively), the minimum flashover voltage becomes higher and approaches that of the 20 centimeter sphere gap. The curve also has become comparatively flat.

Protection at lower overvoltages may be obtained with a flat curve without changing the minimum flashover voltage. This is illustrated by the curve of the smaller type of gap adjusted as shown in figure 7. If the rod gap were set to give the same overvoltage protection instead of the same minimum flashover, the minimum flashover voltage would then be so low as to cause unnecessary interruptions.

The electrodes of several of the gaps shown in figure 7 were spaced alike for comparison. In accordance with the theory that with very high voltages and steep wave fronts the flashover of any 2 electrodes is largely a function of spacing, these curves tend to converge at the short-time flashovers.

CONTROL GAP VERSUS ROD GAP

The difference between a rod gap and a control gap as protective devices for limiting high voltage surges is illustrated in figure 8. Spacings were assumed for the minimum flashover of the rod gap for a number of rated circuit voltages.[8] A rod gap and a control gap were subjected simultaneously to the same surge voltages. At minimum flashover the gaps were adjusted until a balance was obtained, with flashover occurring on either gap. The voltage

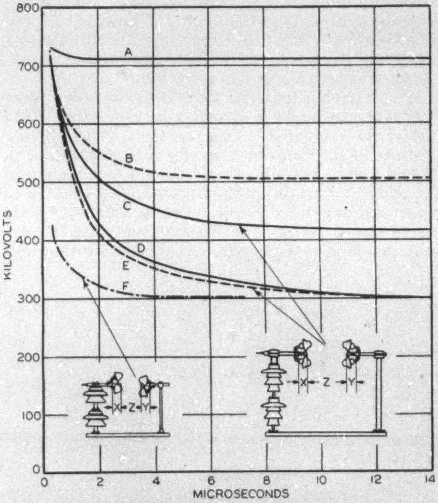


Fig. 7. Comparative volt-time characteristics of control gap as affected by control adjustments

A—50 centimeter sphere gap, 17 inch spacing

B—20 centimeter sphere gap, 17 inch spacing

C—Control gap; Z = 17 inches, X = $6^1/_2$ inches, Y = $8^1/_2$ inches

D—Rod gap, 17 inch spacing

E—Control gap; Z = 17 inches, X = 11 inches, Y = 11 inches

F—Control gap; Z = $10^1/_2$ inches, X = $3^1/_2$ inches, Y = $4^1/_2$ inches was then gradually increased, whereupon all flashovers occurred on the control gap only. When flashovers occurred at the wave crest ($1^1/_2 \times 40$ microsecond wave), the rod gap spacing was decreased until a balance was obtained again. Thus a rod gap spacing of 38 inches (balanced with the control gap at minimum flashover) was reduced to 22 inches to afford the same protection as the control gap at crest flashover ($1^1/_2$ microseconds). The inadequacy of the rod gap for other than a minimum voltage "yardstick" is apparent.

---

[1] For all numbered references see list at end of paper.

That pillar insulators and ring gaps also are inadequate as protective devices is illustrated in figure 9. In the same general voltage range, oscillograms of the 5 types of gaps illustrated were taken at minimum flashover voltage and at 30 per cent overvoltage. The volt-time curve of each is given also. In order to obtain comparable results, the various gap spacings were adjusted so that their minimum flashover voltages would be approximately equal to that of the 3-unit pillar insulator. The oscillograms show the marked difference in time lags. The pillars, rod gap, and ring gap all have relatively long time lags at their minimum flashover voltages, while the control gap and the sphere gap flash over within a few microseconds after the wave crest. With the surge generator charged to 30 per cent higher voltage in each instance, the first 3 gaps flash over appreciably after the crest. The control gap flashover is at the crest of the wave and the spheres flash over on the wave front. The volt-time curves illustrate that for flashovers at 2 microseconds the potentials on the first 3 gaps were increased to about 1000 kv while the control gap flashed over at 700 kv. This represents a voltage increase of over 60 per cent for the first 3 gaps and about 13 per cent for the control gap.

With the control gaps adjusted for flat volt-time characteristics, long time lags at minimum flashover voltages cannot occur just as they cannot occur in sphere gap flashovers. As with sphere gaps, the control gap will flash over with short time lags or not at all.

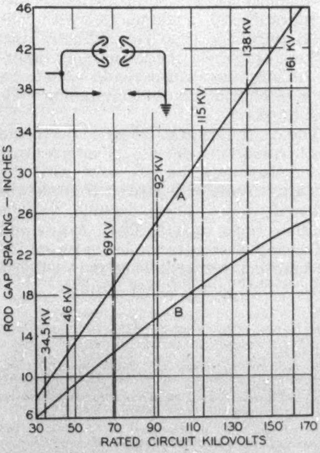


Fig. 8. Rod gap spacing for equivalent control gap protection

A—Minimum flashover

B—$1^1/_2$ microsecond flashover

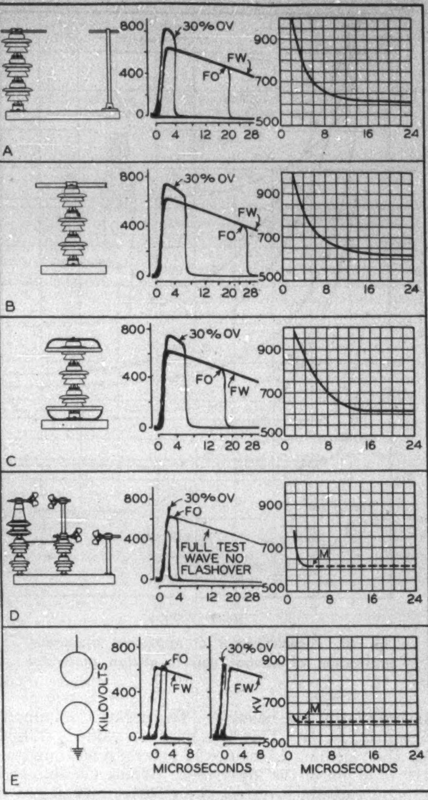


Fig. 9. Comparison of time lag characteristics

A—Rod gap, spacing $38^1/_4$ inches
B—Three station-type pillar insulators
C—Ring gap mounted on station-type pillar insulators, gap spacing 39 inches
D—Dual-gap-type control gap, each gap spacing 13 inches
E—$91^1/_2$ centimeter spheres, spacing 25 centimeters
FO—Minimum flashover
FW—Full wave
OV—Overvoltage
M—Maximum time lag at minimum flashover voltage

Typical Example of Co-ordination

Figure 10 illustrates an application of a control gap for insulation and flashover protection of station equipment. The volt-time curves of both polarities for the bushing do not differ greatly. The minimum positive flashover of the pillars is slightly

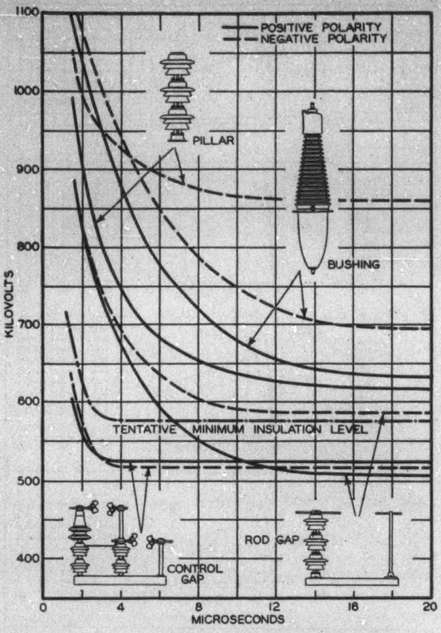


Fig. 10. Characteristics of apparatus, illustrating application of control gap to station protection

below that of the bushing. The negative minimum is much greater. This high negative value is caused by the shielding effect of the porcelain surrounding the base pin of the lower unit. Where the line and ground end are inverted, the positive and negative curves are nearly interchanged.

Such station equipment has high values of flashover voltages at very short time lags. Rod gaps adjusted to protect the equipment for positive minimum voltage flashovers will not protect insulation on negative polarity or on high overvoltages—where protection is most needed. The tentative minimum transformer insulation level shown in figure 10 is in accord with recommendations of the AIEE transformer subcommittee.[1] The entire curve of the control gap on both polarities may be kept below the insulation level and yet maintain a minimum flashover equal to that of the rod gap. Where insulation levels may be higher than that shown, and where lightning arresters are used in connection with the control gap, higher gap spacings may be used. The control gap then acts as backup protection for the arrester to relieve only the extreme higher voltages.

Objections have been raised to the use of gaps as voltage limiting devices for the protection of transformers. These objections are concerned mainly with service interruptions and the possibility of internal insulation damage from chopped waves. That increased stresses resulting from chopped waves can exist may be proved rationally, but although such high internal stresses are possible, they are highly improbable with chopped waves of short duration. Manufacturers have shown that adequate strength against such chopped waves is provided in the present design of transformers.

Effects of Moisture on Operation of Gap

The impulse test results that have been discussed were obtained almost entirely indoors and with the gap dry. In order to ascertain that the gaps will perform satisfactorily under adverse weather conditions, frequent tests were made with a laboratory rain spray. It was found in general that the time characteristics remained practically unchanged and that the minimum flashover voltages under wet conditions were reduced from 15 to 20 per cent. Comparative flashover tests have been conducted also under different humidities. It was found that the measured flashover remained within plus or minus 3 per cent. Tests have been made with absolute humidity ranging between 1 and 9 grains per cubic foot.

Devices for Interrupting Current

The use of some device for interrupting power follow currents is highly desirable. Tests conducted on high voltage fuses and on the deion or expulsion tubes revealed limitations to their use with these gaps. The major objection to fuses is that the gap is rendered inoperative on successive discharges after the initial circuit interruption. This might be partially overcome by the use of some form of reclosure. There would still remain the inconvenience of replacing fuse elements after each operation. The present voltage rating of the expulsion type of tubes is too high to permit their use for station protection. As recommended by the manufacturers at present, such tubes if used in conjunction with control gaps would introduce time lag characteristics that would offset completely the advantages otherwise derived. An ideal installation would seem to be the control type of limiting gap in conjunction with quick reclosing breakers.

Tests are being continued in an effort to overcome the objectionable features of devices for interrupting current in order that they may be used with the control gap. Other forms of insulated controls are being investigated also. These include various forms of insulators, rings, and the like. Horns and other forms of arcing electrodes are being tested for installations where delayed switching may subject the gap to considerable power follow current.

References

1. Recommended Transformer Standards, H. V. Putman and J. E. Clem. Electrical Engineering (AIEE Transactions), v. 53, Dec. 1934, p. 1594–97.

2. An Improved Type of Limiting Gap for Protecting Station Apparatus, A. O. Austin. AIEE Transactions, v. 51, Sept. 1932, p. 676–81.

3. Co-ordination of Insulation, V. M. Montsinger, W. L. Lloyd, Jr., and J. E. Clem. AIEE Transactions, v. 52, June 1933, p. 417–27.

Discussions

Of A.I.E.E. Papers—as Recommended for Publication by Technical Committees

On this and the following 4 pages appear all remaining unpublished discussion, approved by the technical committees, on papers presented at the 1936 AIEE winter convention, New York, N. Y., January 28–31, and on papers presented at the general session of the North Eastern District meeting, New Haven, Conn., May 6–8, 1936. Discussion of papers presented at the 1936 AIEE summer convention, Pasadena, Calif., June 22–26, will be published in later issues as it becomes available. Authors' closures, where they have been submitted, will be found at the end of the discussion on their respective papers.

Tests on Lightning Protection for A-C Rotating Machines

Discussion and author's closure of a paper by E. M. Hunter published in the February 1936 issue, pages 137–44, and presented for oral discussion at the general session of the AIEE North Eastern District meeting, New Haven, Conn., May 8, 1936.

J. F. Calvert and W. G. Roman (Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa.): Certain features of the paper will be discussed in the same order as the author has presented them.

In the first paragraph of the section on tests on protective equipment for machines directly connected to overhead lines the author states that a 250 ohm resistor used in his tests in place of the 250 ohm surge impedance shown in figure 2 of the paper would have given the same results, provided the traveling wave voltage applied to this substituted circuit were twice that applied to the actual circuit of figure 2. This is correct for about 4 microseconds. After that, in the real circuit of figure 2 of the paper, a voltage reflection will return to the machine from the arrester 2,000 feet out on the line, and for some time thereafter successive reflections will return to the machine terminals at intervals of 4 microseconds. These reflections increase the charging rate of the capacitor at the machine terminals; however, they do not occur in the actual test circuit. Calculations indicate that they are important, for when these reflections return to the machine the maximum rate of rise of voltage at the machine terminals may be 2 or more times the initial rate of rise at the machine terminals, resulting from the voltage E_a, which first comes through the line impedance Z of the author's figure 2. It appears that the author's test data may show rates of voltage rise at the machine terminals that are not more than $^1/_2$ as great as they should be for the corresponding actual circuit conditions. Equations for these maximum rates of rise of voltage, with consideration of reflections, are given in appendix II of reference 6 of the paper. Figure 1 of this discussion illustrates how these data are plotted to assist in the correct choice of capacitance to be connected at the machine terminals. This corresponds to the actual circuit of figure 2 of the paper.

The reason for the interest in the maximum rate of voltage rise at the machine terminals is that it is the most useful external measurement for determining the maximum voltage between turns on the first coil of the winding.

If the timing scale on the oscillograms of figure 2 of the paper applies for the machine terminal voltage, the wave reverses in sign in about 20 microseconds. The actual waves due to lightning may be several times that long. It is possible, with long waves applied, for the capacitors to become charged to an undesirably high voltage unless arresters are used between the machine terminals and ground. Another reason for the advisability of arresters at the machine terminals is that there may be a high impedance drop through the ground between the arrester 2,000 feet out on the line and the ground at the machine. Arresters at the machine terminals with their ground connections also connected to the frame of the machine seem to be preferable.

The next practice to be discussed is the use of arresters at the machine terminals connected between lines to form an ungrounded wye. Arresters rated at line-to-ground voltage only, as suggested in the paper, may not clear if all 3 arresters flash. The voltage at the mid-point of this wye no longer is fixed at ground potential. Due to its variations immediately after one arrester extinguishes, the rate of rise of voltage across this one arrester may be such that it will flash again, and thus fail to stay cleared. It would remain cleared if the arresters were rated at nearly line-to-line voltage, but on this basis the arrester might as well be based on line-to-line voltage and be connected to ground. The use of arresters between lines to form a delta eliminates that trouble; however, it is the voltage-to-ground, that is, to the machine iron, that must be limited in order to protect the armature winding, and the arresters should be connected to ground to limit this voltage definitely.

Presumably the author considers using arresters only in an ungrounded wye, or between lines in a delta where there is a star-delta transformer connection between them and the line, that is, when a surge of appreciable length cannot occur simultaneously on all 3 lines. Such arrester connections afford no protection against simultaneous surges on all 3 lines. This point should be made clear to prevent any such applications where surges of this character are possible.

The use of arresters connected to ground at the neutral of ungrounded wye connected armature windings may be discussed profitably. That there can be an overshoot in voltage with respect to the arrester due to the reflection starting before the arrester operates has been recognized for some time. The theoretical magnitude always is reduced greatly by the attenuating effect of the winding. This is due to the coupling between turns instead of the resistance of the armature winding; however, the author seems to overlook the fact that the rating of the neutral arrester can be made appreciably less than the ratings of those at the line terminals. Thus, if even the nearest standard voltage rating is used, the effect of reflection, already greatly reduced by the winding, can be made of negligible importance, if not completely removed.

The lower oscillograph in figure 5 of the paper illustrates the author's other objection to the use of a lightning arrester at the machine neutral. This figure shows a large, sudden drop in voltage at the neutral when

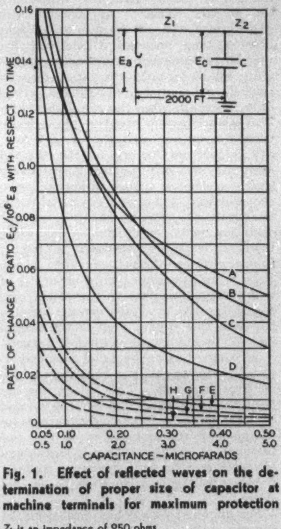


Fig. 1. Effect of reflected waves on the determination of proper size of capacitor at machine terminals for maximum protection

Z_1 is an impedance of 250 ohms
Z_2 is an impedance of 100 ohms
t is the time in seconds after the reflected wave reaches the arrester
T_1 is the time in seconds required for the reflected wave to travel from arrester to capacitor, and is equal to 2.035×10^{-6}

Curves A, B, C, and D are read on the lower scale of abscissas, and curves E, F, G, and H are read on the upper scale

A and E—$t = 7\ T_1$
B and F—$t = 5\ T_1$
C and G—$t = 3\ T_1$
D and H—$t = T_1$

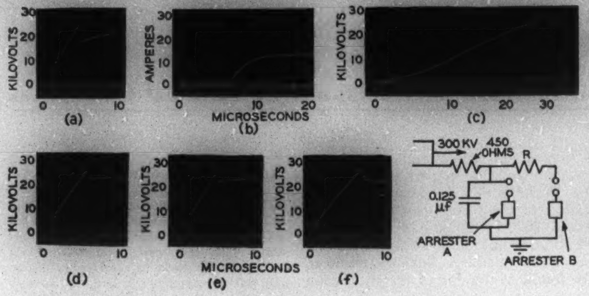


Fig. 2. Oscillograms and diagram of test circuit for determining performance of various arresters

a)—Oscillogram of voltage across a normal arrester with protective ratio of about 2.2
(b)—Oscillogram of current of the same arrester as in (a) with *R* equal to 100 ohms
(c)—Oscillogram showing how the time-current characteristic of the same arrester as in (a) and (b) may be modified by shunting the arrester with a 0.125 microfarad capacitor
(d)—Oscillogram of voltage across an arrester having a 2.5 protective ratio, with *R* equal to 200 ohms
(e)—Same as (d) with *R* equal to 500 ohms
f)—Same as (d) and (e) with *R* equal to 1,000 ohms
All oscillograms are for arrester *B*

the arrester operates; however, the voltage drop does not represent anything inherently wrong with the protective scheme, but merely represents a peculiarity of certain arresters. If the arrester current is small, most arresters with very low protective ratios show this sudden drop to the part of the arrester characteristic that depends on the arrester element. An arrester with slightly higher protective ratio is available, however, and possesses a relatively flat topped volt-ampere characteristic that is quite suitable for application at the machine neutral, and that does not show a serious drop in voltage when the gap flashes over. This protective ratio, based on the maximum normal frequency neutral-to-ground voltage, is quite satisfactory, for the expected surge current is small and it will permit very little overshoot in voltage within the armature winding. The author's tests for determining the voltage drop caused by arrester operation make conditions appear worse than they really are, because he has fed the neutral arrester through only one phase. Such a test determines only about $^1/_3$ of the current, for all phases are involved; consequently, even with the arrester used in his tests, this voltage drop at the neutral probably would have been much less severe.

An alternative to the use of a neutral arrester is the use of large capacitors at the machine terminals. This alternative has been suggested before (see references 4 and 5 of the paper). It has disadvantages, of course: first, the incoming wave must not be too long; second, the cost is greater and increases rapidly with increasing voltage, if higher voltage machines are to be considered.

For machines with graded insulation the arrester at the junction of the high and low voltage windings is safe if an arrester with a relatively flat volt-ampere characteristic is chosen. Even if the arrester did not have such a characteristic, the ordinary arrester could be modified by connecting a small capacitor in parallel with it, as is done at the line terminals. In fact, this could be done at the neutral, for the normal frequency impedance of a 0.125 microfarad capacitor is extremely high.

Figure 2 of this discussion shows the performance of various arresters, although the circuit used might appear to represent a rotating machine with an incoming line. It is not intended for this, but was used merely to limit the rate of voltage rise and the current through arrester *B*. All the data shown in this figure are for the arresters at that position. Figure 2*a* of this discussion shows the voltage across a normal arrester that would have about a 2.2 protective ratio on the gap breakdown and on the element at 1,500 amperes. The severe voltage drop mentioned by the author is shown in that figure. Figure 2*b* shows the reason for the voltage drop, for it may be seen that the arrester current was small. Figure 2*c* shows how this sudden voltage drop may be modified on the same arrester by means of a 0.125 microfarad capacitor in parallel with it. Figures 2*d*, 2*e*, and 2*f* of this discussion show the performance of a 2.5 ratio arrester with a flatter characteristic, using resistors to obtain various values of current through the arrester on discharge. This arrester, with its 2.5 protective ratio, is entirely suitable for use at the machine neutral.

Figure 3 of this discussion shows the voltage at points near the neutral of a machine using an arrester having no sudden voltage drop when the arrester operates. The performance can be closely approximated by the arrester just described.

Figure 4 of this discussion is similar to figure 3, except that it shows the voltage distribution with an arrester at the midpoint of one phase to simulate conditions for a machine with graded insulation.

In figures 3 and 4 of this discussion, 2 taps with consecutive numbers, such as 14 and 15, are separated by 4.5 per cent of the amount of the winding length included in one phase, that is, between the line and neutral of the machine.

E. M. Hunter: J. F. Calvert and W. G. Roman have mentioned that the laboratory circuit used in the tests is not a true equivalent of an overhead transmission line, for it does not allow for reflections in the 2,000-foot area between the line arresters and the protective equipment at the machine terminals. This was recognized when the tests were made, but it is a true representation up to about 4 microseconds, and after that time, even with twice the obtained rate of voltage rise, the stress on the machine insulation probably is not greatly increased; consequently, the test results are considered to be indicative of the effectiveness of the protective system in limiting the transient voltages.

The open-circuit flat-top test voltage waves were about 100 microseconds long, which probably is representative of single lightning transients. The 0.5-microfarad capacitor was not charged to a voltage sufficiently high to permit an arrester to func-

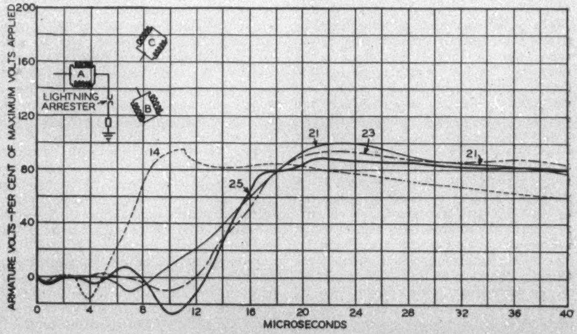


Fig. 3. Curves showing voltage distribution near the neutral of the winding of a machine protected by an arrester not characterized by rapid voltage drop during operation

Numbers on curves indicate winding tap numbers; tap 14 is the mid-point of the winding

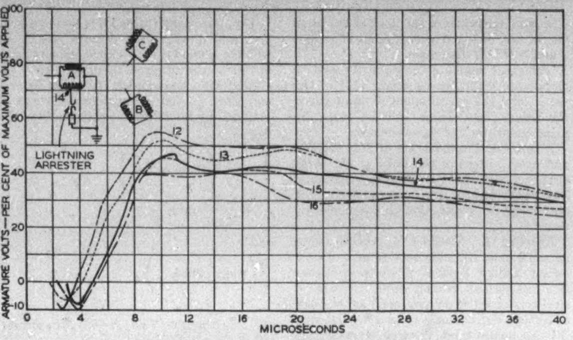


Fig. 4. Curves showing voltage distribution near the neutral of the same machine as in figure 3, but with arrester connected to mid-point of one phase

tion; consequently, it is difficult to justify economically an arrester in parallel with the capacitor. The proposed ungrounded star-connection of arresters can be used with any transformer connection except the star-star. With all other transformer connections the electromagnetic voltage component enters the low-voltage side of the transformer phase-to-phase, so that only 2 of the arresters conduct simultaneously. The discussion of this connection in the paper was limited to its use with a star-delta transformer, the most common one in use at generating stations.

If there is available commercially an arrester with characteristics as described by Calvert and Roman, it should be suitable for use at machine terminals; however, such an arrester should have approximately the same impedance characteristic for a current range of at least 3 to 1, depending upon whether the transient enters the neutral over 1, 2, or all 3 phases of the machine simultaneously. Figures 2*d*, 2*e*, and 2*f* of their discussion give the voltagetime characteristics of the proposed arrester. A comparison of oscillograms *d* and *f* of figure 2 shows that with reduced current through the arrester (higher *R*) the difference between the gap breakdown and arrester impedance curves increases. The voltage difference on oscillogram *f* is about $^2/_3$ of that shown by oscillogram *a*.

Equivalent Circuits—2 Coupled Circuits

Discussion of a paper by J. C. Balsbaugh, R. B. Gow, W. P. Douglass, and A. H. Leal published in the April 1936 issue, pages 366–71, and presented for oral discussion at the general session of the AIEE North Eastern District meeting, New Haven, Conn., May 8, 1936.

E. W. Kimbark (Massachusetts Institute of Technology, Cambridge): This paper is a valuable contribution to the literature on equivalent circuits. The writer would like to discuss the following 3 topics: (1) an equivalent circuit alternative to that shown in figure 3 of the paper for the general case of 2 coupled circuits not connected to busses at either end; (2) nominal or approximate values of the links of the equivalent circuits, with numerical comparisons of the nominal values with the exact values; (3) application of the equivalent circuits to 2 parallel lines of different voltages, using different voltage scales for each line.

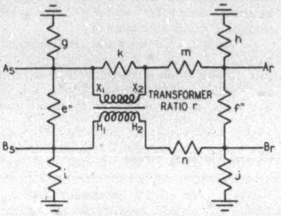


Fig. 1. An alternative equivalent circuit for the representation of 2 coupled circuits not connected to busses at either end

The alternative circuit, shown in figure 1 of this discussion, has 9 impedance links and a transformer. The following assumptions are made concerning the transformer:

(1). For the sake of generality, it has a turn ratio *r*, although commonly a one to one ratio is most convenient.

(2). The polarity is subtractive, as indicated in figure 1 of this discussion, but the formulas to be given apply to additive polarity if *r* is considered to be a negative number.

(3). Exciting admittance and leakage impedance are negligible. If they are not, corrections may be made by reducing the calculated admittance of link *k* by the amount of the exciting admittance referred to the low voltage side and by reducing the calculated impedance of link *n* by the amount of the leakage impedance referred to the high voltage side.

The new circuit will be referred to as the "transformer circuit," and the one in figure 3 of the paper as the "mesh circuit."

There is a transformer circuit equivalent to any given mesh circuit, provided that links *c* and *d* of the latter are equal, which is true for the cases considered in the paper. For equivalence, the links of the transformer circuit must have the following values in terms of the links of the mesh circuit:

$$\left.\begin{aligned} k &= -\frac{abc}{r(c^2 - ab)} \\ m &= \frac{bc(c + a/r)}{c^2 - ab} \\ n &= \frac{ac(c + rb)}{c^2 - ab} \\ \frac{1}{e''} &= \frac{1}{f''} = \frac{1}{e} + \frac{1}{c} \end{aligned}\right\} \quad (1)$$

or inversely:

$$\left.\begin{aligned} a &= \frac{\Delta}{k + m} \\ b &= \frac{\Delta}{r^2k + n} \\ c &= d = -\frac{\Delta}{rk} \\ \frac{1}{e} &= \frac{1}{f} = \frac{1}{e''} + \frac{rk}{\Delta} \end{aligned}\right\} \quad (2)$$

where

$$\Delta = mn + kn + r^2km$$

Links *g*, *h*, *i*, and *j* are the same in both circuits.

The equivalence of the 2 circuits and the relations between their links may be proved by considering the central part of the transformer circuit, consisting of links *k*, *m*, *n*, and the transformer, and finding the equivalent 4 terminal mesh (arranged like figure 7 of the paper, but without regard to the notation of that figure). The horizontal links *a* and *b* and the diagonal links *c* and *d* have the impedance values given by equations (2) of this discussion, but the vertical links $e' = f' = -c = -d$. Now let links *e* and *f* of the original mesh circuit each be split into 2 parallel branches, one $e' = f'$, having the value just given, and the other $e'' = f''$ being whatever is left. Links e'', f'', *g*, *h*, *i*, and *j* are left unchanged, while links *a*, *b*, *c*, *d*, e', and f' are replaced by *k*, *m*, *n*, and the transformer.

The following advantages are claimed for the transformer circuit: The values of the impedances of the links bear a more direct relation to the fundamental physical constants of the lines than do those of the mesh circuit, thus facilitating the computation of nominal values of these impedances, as is explained later; in particular, the use of the transformer circuit may (as verified by numerical examples given later) eliminate links with negative resistance, which are difficult to represent on the network analyzer.

On the contrary, where the equivalent circuit forms part of a network that is to be reduced by computation of star-mesh transformations, the negative resistance is not objectionable, and the mesh form of equivalent circuit is believed to be preferable.

The distinction between the nominal π and the equivalent π circuits of a single transmission line is well known. The links of the nominal π (refer to figure 5 of the paper) are

$$\left.\begin{aligned} a &= Z_{AA}L \\ \frac{1}{b} &= \frac{1}{c} = \frac{1}{2}\,Y_{AA}L \end{aligned}\right\} \quad (3)$$

The links of the equivalent π are, however,

$$\left.\begin{aligned} a &= Z_{AA}L\,(\sinh\theta)/\theta \\ \frac{1}{b} &= \frac{1}{c} = \frac{1}{2}\,Y_{AA}L\,\frac{\tanh(\theta/2)}{\theta/2} \end{aligned}\right\} \quad (4)$$

where

$$\theta = \sqrt{Z_{AA}Y_{AA}}L$$

For short lines (θ being small) the correction factors $\frac{\sinh\theta}{\theta}$ and $\frac{\tanh(\theta/2)}{\theta/2}$ are nearly equal to unity; under this condition the nominal π is a good approximation to the exact equivalent circuit.

To derive an analogous nominal circuit for 2 coupled transmission lines, start by representing the total self and mutual series impedances of the lines, by a Y circuit with links k, m, and n; introduce a transformer of ratio one to one to insulate the lines from each other (so far this is an exact equivalent circuit for magnetically coupled lines with no shunt admittance); next provide a delta between the 2 lines and ground to represent the total self and mutual shunt admittances; split this delta into halves and attach half to each end of the lines. The result is the transformer circuit shown in figure 1 of this discussion. The nominal values of the links for transformer ratio r are:

$$\left.\begin{aligned} k &= Z_{AB}L/r \\ m &= (Z_{AA} - Z_{AB}/r)L \\ n &= (Z_{BB} = r\,Z_{AB})L \\ \frac{1}{e''} &= \frac{1}{f''} = -\,\frac{1}{2}Y_{AB}L \\ \frac{1}{g} &= \frac{1}{h} = \frac{1}{2}\,(Y_{AA} + Y_{AB})L \\ \frac{1}{i} &= \frac{1}{j} = \frac{1}{2}\,(Y_{BB} + Y_{AB})L \end{aligned}\right\} \quad (5)$$

Table I—Comparison of Exact and Nominal Values

Link	Exact Value	Nominal Value
$a = b$	$203\angle 83.3°$ ohms	$206\angle 82.7°$ ohms
$c = d$	$488\angle -92.4°$ ohms	$486\angle -91.6°$ ohms
$e = f$	$492\angle 87.0°$ ohms	$487\angle 88.1°$ ohms
$\frac{1}{g} = \frac{1}{h} = \frac{1}{i} = \frac{1}{j}$	$156 \times 10^{-6}\angle 89.0°$ mhos	$154 \times 10^{-6}\angle 90.0°$ mhos
k	$102\angle 77.2°$ ohms	$105\angle 74.5°$ ohms
$m = n$	$143\angle 85.0°$ ohms	$144\angle 84.4°$ ohms
$\frac{1}{e''} = \frac{1}{f''}$	$29 \times 10^{-6}\angle 38°$ mhos	$8 \times 10^{-6}\angle 90°$ mhos

The nominal values of the links of the mesh circuit may be found by combining equations 2 and 5 of this discussion.

The exact values of the links of the mesh circuit are given by equations (11) of the paper, and the exact values of the links of the transformer circuit may be found by using equations 1 of this discussion.

A numerical comparison of the nominal and exact values of the links of the mesh circuit is given in the following examples. The exact values were computed by the authors of the paper, though not published therein.

Example 1. Consider a zero sequence network of a 100 mile section of a double circuit 220-kv 3-phase 60-cycle transmission line without ground wires; there are 6 steel reinforced aluminum conductors, each of 795,000 circular mils cross sectional area (54 aluminum and 7 steel strands) arranged in a horizontal plane 110 feet above ground; the spacing is 25 feet between phases and 125 feet between circuits. The circuit constants are

$Z_{AA} = Z_{BB} = 2.48\angle 80.2°$ ohms per mile
$Z_{AB} = 1.05\angle 74.5°$ ohms per mile
$Y_{AA} = Y_{BB} = 3.25 \times 10^{-6}\angle 90.0°$ mhos per mile
$Y_{AB} = 0.166 \times 10^{-6}\angle -90.0°$ mhos per mile
L = length = 100 miles

All values agree (table I) within a few per cent in magnitude and within a few degrees in angle except $1/e''$ and $1/f''$, which are negligibly small admittances.

Example 2. Consider the zero sequence network of a 100 mile section of single circuit 220-kv 3-phase 60-cycle transmission line with ground wires. There are 3 line wires, as in example 1; there are also 2 ground wires, each a 266, 800 circular mil, steel reinforced aluminum conductor (26 aluminum and 7 steel strands). They are spaced 35 feet apart and are 20 feet above the line wires. The towers are spaced 500 feet apart. The tower footing resistance is 0.333 ohm per tower. Circuit A represents the line wires, circuit B the ground wires. The circuit constants are

$Z_{AA} = 2.49\angle 80.2°$ ohms per mile
$Z_{BB} = 3.02\angle 71.0°$ ohms per mile
$Z_{AB} = 1.05\angle 74.3°$ ohms per mile
$Y_{AA} = 3.72 \times 10^{-6}\angle 90.0°$ mhos per mile
$Y_{BB} = 10.64\angle 1.3°$ mhos per mile
$Y_{AB} = 1.10 \times 10^{-6}\angle -90.0°$ mhos per mile
L = 100 miles

The agreement (table II) is poor on links a, i, and j, which are directly associated with the ground wires. This is not surprising in view of the excessive shunt leakage of the ground wires through the low tower footing resistance. A better approximation may be obtained by resorting to equations 22 of the paper:

$$\frac{1}{i} = \frac{1}{j}\left(\text{there called } \frac{1}{g} = \frac{1}{h}\right) = \frac{\theta}{Z_{BB}L}\tanh\frac{\theta}{2}$$

and

$$\frac{1}{a}\left(\text{there called } \frac{1}{d}\right) = \frac{\theta}{Z_{BB}L\sinh\theta} - \frac{Z_{AB}^2}{(Z_{AB}^2 - Z_{AA}Z_{BB})Z_{BB}L}$$

where

$$\theta = \sqrt{Z_{BB}Y_{BB}}L = 568\angle 36.2°$$

For such a large value of θ

$$\tanh\frac{\theta}{2} \approx 1 \text{ and } \sinh\theta \approx \infty$$

Hence

$$\frac{1}{i} = \frac{1}{j} = \frac{\theta}{Z_{BB}L} = \sqrt{\frac{Y_{BB}}{Z_{BB}}} = \sqrt{\frac{10.64\angle 1.3°}{3.02\angle 71.0°}} = 1.88\angle -34.8° \text{ mhos}$$

$$a = -\frac{[(Z_{AB}L)^2 - (Z_{AA}L)(Z_{BB}L)]Z_{BB}L}{(Z_{AB}L)^2} = -\frac{CZ_{BB}}{Z_{AB}} \times \frac{\angle 180.0° \times 612\angle -102.6° \times 3.02\angle 71.0°}{2.49\angle 80.2°} = 1760\angle 74.1° \text{ ohms}$$

These values of a, i, and j agree fairly well with the exact values. Impedance $i = j$ will be recognized as the characteristic impedance of the ground wires.

Example 3. The zero sequence network of a 5 mile section of a 66-kv 3-phase 60-cycle underground transmission line, consists of 3 single conductor lead covered 750,000 circular mil cables, spaced 6 inches center to center, bonded together and grounded through 3.33 ohms resistance every 500 feet. Circuit A represents the conductors, circuit B the sheaths. The circuit constants are

$Z_{AA} = 3.16\angle 83.0°$ ohms per mile
$Z_{BB} = 3.06\angle 74.2°$ ohms per mile
$Z_{AB} = 3.00\angle 84.4°$ ohms per mile
$Y_{AA} = -Y_{AB} = 135 \times 10^{-6}\angle 89.4°$ mhos per mile
$Y_{BB} = 1.06\angle 0.1°$ mhos per mile
L = 5 miles

The agreement between the exact and nominal values (table III) in the last example is much poorer than in the other 2 examples, probably because of the close electromagnetic and electrostatic coupling between circuits A and B.

It will be noted that in every case links c and d have negative resistance components and have a complex impedance nearly equal and opposite to that of links e and f.

Table II—Comparison of Exact and Nominal Values

Link	Exact Value	Nominal Value
a	$1720 \angle 74.2°$ ohms	$258 \angle 71.5°$ ohms
b	$209 \angle 80.8°$ ohms	$213 \angle 80.7°$ ohms
$c = d$	$600 \angle -102.5°$ ohms	$612 \angle -102.6°$ ohms
$e = f$	$625 \angle 77.5°$ ohms	$633 \angle 77.0°$ ohms
$\frac{1}{g} = \frac{1}{h}$	$122 \times 10^{-6} \angle 88.3°$ mhos	$131 \times 10^{-6} \angle 90.0°$ mhos
$\frac{1}{i} = \frac{1}{j}$	$1.86 \angle -34.9°$ mhos	$532 \angle 1.3°$ mhos
k		$105 \angle 74.3°$ ohms
m		$145 \angle 84.4°$ ohms
n		$197 \angle 69.1°$ ohms
$\frac{1}{e''} = \frac{1}{f''}$		$55 \times 10^{-6} \angle 90.0°$ mhos

These examples will give some idea of the cases in which the exact values must be used and those in which approximate values will suffice. In any case, the availability of the exact formulas developed by the authors is valuable for checking the validity of short cut methods.

Improper operation of ground relays sometimes results from zero sequence current induced in a line from a parallel line of different voltage. The equivalent circuits given in the paper may be used to represent such lines. When solving power networks it is customary to use different voltage and current scales for parts of the network having different nominal voltages, or, if per unit quantities are employed, to use different bases of voltage, current, and impedance. Whether the coupled circuits A and B, to be represented by the equivalent circuits under discussion, may have different voltage scales, or different base voltages must be determined.

The differential equations 1 of the paper have exactly the same form when written in per unit quantities with different base voltages for each line as they do when written in actual quantities. It follows that the equivalent circuits will give the true per unit voltages and currents at each end of each line, if all the links of the equivalent circuits are calculated from per unit values of the self and mutual impedances and admittances. If s is the ratio of the base voltage of line A to the base voltage of line B, then the base impedance for line B is $1/s^2$ times, and the base impedance for Z_{AB} is $1/s$ times, the base impedance for line A. In using the transformer equivalent circuit on the network analyzer it probably is advisable to use a transformer ratio r nearly equal, though not necessarily exactly equal, to the ratio s of the base voltages; otherwise, either m or n may have a negative resistance component.

Table III—Comparison of Exact and Nominal Values

Link	Exact Values, Ohms	Nominal Values, Ohms
a	$3.43 \angle -1.0°$	$3.39 \angle 4.3°$ $3.64 \angle -73°$*
b	$3.28 \angle 19.4°$	$3.50 \angle 13.1°$
$c = d$	$3.34 \angle -170.6°$	$3.57 \angle -177.1°$
$e = f$	$3.40 \angle 8.4°$	$3.57 \angle 2.9°$
$g = h$	$142 \angle 79.9°$	∞
$i = j$	$1.67 \angle 38.9°$	$0.379 \angle -0.1°$ $1.81 \angle 35.0°$*
k		$15.0 \angle 84.4°$
m		$0.87 \angle 30.9°$
n		$2.73 \angle -2.9°$
$e'' = f''$		$2{,}960 \angle -89.4°$

* These values of a, i, and j are computed from equations 22 of the paper.

Frequency Tripling Transformers

Discussion of a paper by J. L. Cantwell published in the July 1936 issue, pages 784–90, and presented for oral discussion at the general session of the AIEE North Eastern District meeting, New Haven, Conn., May 6, 1936.

P. W. Blye (Bell Telephone Laboratories, Inc., New York, N. Y.): As mentioned in the introduction of the paper, the presence of harmonics in power systems may, if the harmonics are of sufficient magnitude, result in inductive interference in neighboring telephone circuits. For several years there has been a trend toward improved wave shape on power systems and a better balance of telephone circuits and apparatus through the co-operative efforts of electrical manufacturers and power and telephone companies. As a result, satisfactory inductive co-ordination may be effected between the usual types of power and telephone circuits by relatively simple and inexpensive methods.

Contrary to this recent trend, in the frequency tripler described by the author the transformers are intentionally excited to a degree giving the greatest possible generation of harmonics. Although components of the triple harmonic series are excluded from the supply circuit, relatively large harmonic currents of another series may exist in the line wires. The extensive commercial use of devices of this character, particularly in the larger sizes, might be decidedly detrimental to system wave shape, and necessarily would be viewed with concern by telephone companies. In any particular case where a frequency tripler of this type is proposed, careful consideration of its possible effects on neighboring telephone circuits would seem to be desirable. As a part of the development work on this project, means for absorbing the large harmonic components that might otherwise find their way to the line conductors also seems to be desirable.

Electrical Equipment for Waterworks Systems

Discussion and author's closure of a paper by S. A. Canariis published in the January 1936 issue, pages 36–40, and presented for oral discussion at the automatic stations session of the winter convention, New York, N. Y., January 29, 1936.

P. A. Borden (Bristol Co., Waterbury, Conn.): Electrical engineers connected with utilities, communication systems, or manufacturers of equipment, are likely to overlook the applications of telemetering in other fields, particularly in pipe line and waterworks systems. The author refers to a telemetering system in which time is the measuring unit, both a-c and d-c impulses being transmitted over a common circuit. There are several methods of telemetering to which that description applies. More complete data would be of interest, so that a positive identification of his telemetering equipment may be made, and the system placed in its proper classification.

S. A. Canariis: The telemetering system referred to in the paper is a Bristol Company "metameter." Transmitter and receiver are both operated at 4 rpm by synchronous drives, energized separately, but from the same 60 cycle system. During each revolution of the transmitter cam, the pressure gauge arm closes and opens a mercury switch, thereby energizing or de-energizing the transmitting circuit. The energized and de-energized periods, totaling 15 seconds, are in direct proportion to the position of the gauge arm, and the indicator arm will assume a corresponding position affected only by variation in the proportioning of the 15 second time period.

The use of a supervisory control transmitting circuit for simultaneous transmission of telemetering impulses is of interest. The 60 cycle transmitting current is supplied through a 115 to 115 volt, 150 volt-ampere power limiting output transformer. The transmitter switch is operated at 115 volts, which is then stepped down by means of a 115 to 25 volt transformer. The secondary of the latter transformer is connected in parallel with the supervisory control transmitting circuit, and a 4 microfarad capacitor is inserted in one branch to prevent short circuiting of the d-c supervisory system through the secondary. The impulses are transmitted at about 3 milliamperes over approximately 5 miles of standard telephone circuits to Herron Hill pumping station, where the supervisory control dispatcher's panel is located. The supervisory circuit is tapped through a 0.5 microfarad capacitor and connected to a full wave copper oxide rectifier, which changes the a-c telemetering impulses to d-c impulses for operation of a telephone clapper type relay; the contacts of the relay close a local 115 volt a-c circuit through a resistor, applying a 45 milliampere current at 40 volts to the a-c magnet in the telemeter receiver. The supervisory control system referred to in the paper is a Westinghouse "visicode" system operating on direct current at 40 volts.

News
Of Institute and Related Activities

South West District Meeting Offers Attractive Program

As ANNOUNCED in previous issues, Dallas, Texas, will be host to a 3-day meeting of the South West District of the AIEE, which will be held from Monday to Wednesday, October 26–28, 1936. Headquarters will be at the Adolphus Hotel where 5 technical sessions, 2 student sessions, several luncheon meetings, and the dinner-dance will be held. An attractive program is offered and those who will attend are especially urged to do so for the full duration of the meeting.

Dallas, a smartly cosmopolitan city, with its business center, beautiful residential sections, parks, and fine hotels provides an ideal location for the meeting. The $25,000,000 Texas Centennial Exposition will be an added attraction, and the committee has co-ordinated the program so that some of the features may be seen to special advantage. The lighting spectacle alone which demonstrates the value and adaptability of modern lighting, not to mention the Hall of Electricity and Communications Building, air conditioning and industrial exhibits, numerous transformer stations, and sources of electrical supply, holds much of unusual interest for the electrical engineer. The exposition is said to be the best-lighted "World's Fair" in history, having the equivalent of 86,000 watts in lamps per acre, and to set a new record of achievement in spectacular exposition lighting.

TECHNICAL SESSIONS

Papers of general interest and with particular appeal to members of the Southwest will be presented and discussed in 5 technical sessions. Some of the interesting subjects are: a new telephotograph system, electrical features of the Texas Centennial Exposition, carrier current relaying, lightning and surge protection, rural electrification, electric arc welding, and d-c equipment for oil well drilling. In addition there will be 2 student technical sessions at which papers will be presented by students.

ENTERTAINMENT

The following is a tentative outline of the entertainment program as arranged by the entertainment and reception committee.

Monday noon a joint luncheon with the Dallas Electric Club will be held in the Crystal Ballroom of the Baker Hotel with Dr. M. Luckiesh, director of the lighting research laboratories of the General Electric Company, Cleveland, Ohio, as the luncheon speaker; he has the reputation of being an excellent speaker. The women are invited to this luncheon and there will be favors for them. In the afternoon the women will be conducted on a tour through the Centennial grounds. Among the points of interest included in this tour are: the Rangers' headquarters cabin, replica of the Alamo, aquarium, Museum of Natural History, and State of Texas Building. It is suggested that the women have dinner in a group at one of the excellent cafés or tea rooms on the Centennial grounds.

Monday evening at 7:30 p.m. the women are invited to take part in the inspection of the lighting effects, loud speaker system, and other electrical features of the Centennial. Following the inspection tour, the night clubs and shows will be visited.

Tuesday afternoon and evening a comprehensive program has been planned for the women which includes special showings on the Centennial grounds, tea in the penthouse on the Chrysler roof and a dinner-dance at 7:30 on the Adolphus Hotel roof.

On Wednesday, sightseeing tours of the city and of the Centennial have been arranged for the women.

SPORTS

A special golf tournament has not been arranged, because it is believed that the Centennial will attract too many away from the golf course to permit a tournament; but arrangements have been made for all of the 6 fine golf clubs of Dallas to be open to convention attendants upon payment of a very nominal greens fee.

INSPECTION TRIPS

Monday afternoon there will be inspection trips as listed in the program, to the Texas Centennial Central Exposition, an 8,500-kw generating station, an underground network system, a telephone toll office, and a low-cost farm-electrification project. In the evening the lighting effects and other electrical features of the exposition will be seen.

HOTELS AND REGISTRATION

Members are urged especially to make their hotel reservations *early* by writing directly to the hotel of their preference. There are several good hotels in Dallas including the Adolphus (headquarters), Baker, Hilton, Jefferson, Sanger Hotel and apartments, and Stonleigh Hotel and apartments. The rates vary from $2 to $6 per room.

Members who will attend the meeting should also register in advance by filling in and mailing the advance-registration card which will be sent to the membership of the South West District and nearby territory. This will permit the committee to have badges ready and thus avoid congestion at the registration desk where registration should be completed promptly upon arrival.

RULES ON PRESENTING AND DISCUSSING PAPERS

At the technical sessions, papers may be presented in abstract, 15 minutes being allowed for each paper unless otherwise arranged or the presiding officer meets with the authors preceding the session to arrange the order of presentation and allotment of time for papers and discussion.

Any member is free to discuss any paper when the meeting is opened for general discussion. Usually 5 minutes is allowed to each discusser for the discussion of a single paper or of several papers on the same general subject. When a member signifies his desire to discuss several papers not dealing with the same general subject, he may be allowed a somewhat longer time.

It is preferable that a member who wishes to discuss a paper give his name in advance to the presiding officer of the session at which the paper is to be presented. Each discusser is to step to the front of the room and announce, so that all may hear, his name and professional affiliations. Three typewritten copies of discussion prepared in advance should be left with the presiding officer.

Other discussions to be considered for publication should be typewritten (double spaced) and submitted in triplicate to C. S. Rich, secretary of the technical program committee, AIEE headquarters, 33 West 39th St., New York, N. Y., on or before November 12, 1936. Discussion of unpublished addresses and papers need not be submitted.

COMMITTEES

General Meeting Committee: L. T. Blaisdell, vice president, South West District, *chairman;* E. W. Burbank, Lee E. Cook, A. B. Emrick, E. T. Gunther, B. D. Hull, H. G. Mathewson, F. J. Meyer, and John Oram.

Meetings and Papers Committee: Lee E. Cook, *chairman;* R. F. Danner.

Entertainment and Reception Committee: A. B. Emrick, *chairman;* G. B. Richardson, and Stanley Zercher.

Attendance and Publicity Committee: John Oram. *chairman.*

Transportation and Inspection Committee: H. G. Mathewson, *chairman.*

Hotels and Registration Committee: E. W. Burbank, *chairman.*

Student Activities Committee: J. S. Waters, *chairman.*

Finance Committee: E. T. Gunther, *chairman.*

Program

Monday, October 26

9:00 a.m.—Registration
Adolphus Hotel Lobby

10:00 a.m.—Opening of Meeting
Adolphus Hotel Junior Ball Room. Presiding: L. T. Blaisdell, vice president, South West District, AIEE.

ADDRESS OF WELCOME, Mayor George Seargant of Dallas.

TEXAS—THE OCTOBER HEADQUARTERS OF THE AIEE, A. M. MacCutcheon, President, AIEE.

General Technical Session
Presiding: F. J. Meyer and N. F. Rode.

A DISTURBANCE DURATION RECORDER, C. H. Frier, Oklahoma Gas and Electric Company.
September issue, p. 1025–8

A NEW TELEPHOTOGRAPH SYSTEM, F. W. Reynolds, Bell Telephone Laboratories, Inc.
September issue, p. 996–1006

ELECTRICAL FEATURES OF TEXAS CENTENNIAL CENTRAL EXPOSITION, John Fies, Texas Centennial Central Exposition.
Scheduled for October issue

12:15 p.m.—Luncheon meeting jointly with Dallas Electric Club
Baker Hotel, Crystal Ball Room.

Luncheon speaker: M. Luckiesh, General Electric Company (women and guests invited).

1:30 p.m.—Inspection Trips

1. Texas Centennial Central Exposition.
2. Dallas Power and Light Company 85,000 kw generating station.
3. Dallas Power and Light Company underground network system.
4. Southwestern Bell Telephone Company toll office.
5. Texas Power and Light Company low-cost farm-electrification project.

In this program, reference to the issue and, in so far as possible, to the page in ELECTRICAL ENGINEERING, is given for all papers

7:30 p.m.—Inspection Trips

Lighting effects and other electrical features, Texas Centennial Central Exposition (assemble on main esplanade at exposition; women and guests invited).

Tuesday, October 27

9:00 a.m.—Student Technical Session
Adolphus Hotel, Roof Garden.

9:00 a.m.—General Technical Session
Adolphus Hotel, Junior Ball Room. Presiding: Stanley Stokes and L. C. Starbird.

*LIGHTNING AND SURGE PROTECTION, J. B. Hodtum, Allis-Chalmers Manufacturing Company.

*SUBSTATION GROUNDING PRACTICES, C. E. Bathe, Oklahoma Gas and Electric Company.

*IMPROVED SERVICE CONTINUITY BY RAPID RECLOSURE OF BREAKERS, R. E. Powers, Westinghouse Electric and Manufacturing Company, R. E. Pierce, Electric Bond and Share Company, E. C. Stewart, Arkansas Power and Light Company, and G. E. Heberlein, Westinghouse Electric and Manufacturing Company.

12:15 p.m.—Luncheon Meeting of Committee on Student Activities
Adolphus Hotel, Parlor B (6th floor).

12:15 p.m.—Luncheon Meeting of District Executive Committee
Adolphus Hotel.

2:00 p.m.—Student Technical Session
Adolphus Hotel, Roof Garden.

2:00 p.m.—General Technical Session
Adolphus Hotel, Junior Ball Room. Presiding: Walker Mier and R. F. Danner.

*DIRECT CURRENT EQUIPMENT FOR OIL WELL DRILLING, D. H. Levy, Magnolia Petroleum Company, and W. C. Dreyer, Westinghouse Electric and Manufacturing Company.

A TRANSMISSION SYSTEM FOR TELETYPEWRITER EXCHANGE SERVICE, R. E. Pierce and E. W. Bemis, American Telephone and Telegraph Company.
September issue, p. 961–70

SWITCHBOARDS AND SIGNALING FACILITIES OF THE TELETYPEWRITER EXCHANGE SYSTEM, A. D. Knowlton, G. A. Locke, and F. J. Singer, Bell Telephone Laboratories, Inc.
September issue, p. 1015–25

7:30 p.m.—Dinner-Dance
Adolphus Hotel, Roof Garden.

Wednesday, October 28

9:00 a.m.—General Technical Session
Adolphus Hotel, Junior Ball Room. Presiding: D. D. Clarke and M. H. Lovelady.

*DESIGN AND CONSTRUCTION OF FARM ELECTRIFICATION LINES, Jack Sheehan, Houston Lighting and Power Company.

*ELECTRIC ARC WELDING, O. A. Tilton, General Electric Company.

EXPERIENCES WITH A MODERN PROTECTIVE RELAY SYSTEM, G. W. Gerell, Union Electric Light and Power Company.
Scheduled for October issue

2:00 p.m.—General Technical Session
Adolphus Hotel, Junior Ball Room. Presiding: J. B. Thomas and B. D. Hull.

*APPLICATION OF SHUNT CAPACITORS TO DISTRIBUTION CIRCUITS, F. M. Starr, General Electric Company, and G. P. Gamble, Union Electric Light and Power Company.

*PRESENT TRENDS IN CARRIER SYSTEMS, H. P. Lawther, Southwestern Bell Telephone Company.

Illustrated lecture: THE ELECTRON THEORY, R. G. Kloeffler, Kansas State College.

---

* These papers are scheduled for presentation, but at the time of going to press they have not been accepted for publication.

Skyline of Dallas, Texas, where the Institute's South West District will meet October 26–28, 1936. The Adolphus Hotel (outlined) will be headquarters for the meeting

AIEE Directors Meet at Institute Headquarters

The regular meeting of the board of directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, on August 4, 1936.

Present: *President*—A. M. MacCutcheon, Cleveland, Ohio. *Past-Presidents*—E. B. Meyer, Newark, N. J.; J. B. Whitehead, Baltimore, Md. *Vice Presidents*—O. B. Blackwell, New York, N. Y.; Mark Eldredge, Memphis, Tenn.; C. Francis Harding, Lafayette, Ind.; A. C. Stevens, Schenectady, N. Y. *Directors*—F. M. Farmer, New York, N. Y.; H. B. Gear, Chicago, Ill.; C. R. Jones, New York, N. Y.; P. B. Juhnke, Chicago, Ill.; W. B. Kouwenhoven, Baltimore, Md.; Everett S. Lee, Schenectady, N. Y.; K. B. McEachron, Pittsfield, Mass.; C. A. Powel, East Pittsburgh, Pa. *National Treasurer*—W. I. Slichter, New York, N. Y. *National Secretary*—H. H. Henline, New York, N. Y.

The minutes of the board of directors meeting of June 24, 1936, were approved.

A resolution was adopted in memory of Dean G. C. Shaad, a director of the Institute, who died on July 9, 1936.

F. Ellis Johnson, dean of the college of engineering, University of Missouri, Columbia, was elected a director of the Institute, for the unexpired term, ending July 31, 1939, of G. C. Shaad, deceased.

A report of a meeting of the board of examiners on July 22, 1936, was presented and approved. Upon recommendation of the board of examiners, the following actions were taken: 2 applicants were transferred to the grade of Fellow; 16 applicants were elected and 36 were transferred to the grade of Member; 126 applicants were elected to the grade of Associate; 31 Students were enrolled.

The finance committee reported disbursements in July amounting to $32,759.33, and the report was approved.

Upon recommendation of the conference of officers, delegates, and members in June 1936, the board authorized the payment of traveling expenses of alternates for Student Branch chairmen to District conferences on student activities, upon recommendation of the vice president of the District in each case, and authorized an annual appropriation of $5 per Branch participating toward the expenses of student conferences and conventions.

Announcement was made of the appointment by the president of Institute committees for the administrative year beginning August 1, 1936 (a list of the committees and representatives of the Institute appears elsewhere in this issue).

The board confirmed the appointment by the president of Mr. H. P. Charlesworth as chairman of the Edison Medal committee for the year beginning August 1, 1936, and of G. L. Knight, H. W. Osgood, and W. S. Rodman as members of the committee for the term of 2 years beginning August 1, 1936. From its own membership, the board elected F. M. Farmer, C. E. Rogers, and A. C. Stevens to serve on the Edison Medal committee for the term of 5 years beginning August 1, 1936.

The board confirmed the appointment by the president of Vannevar Bush, C. R. Jones, and D. C. Prince as members of the Lamme Medal committee for the term of 3 years, and of N. E. Funk as chairman for the term of one year, beginning August 1, 1936.

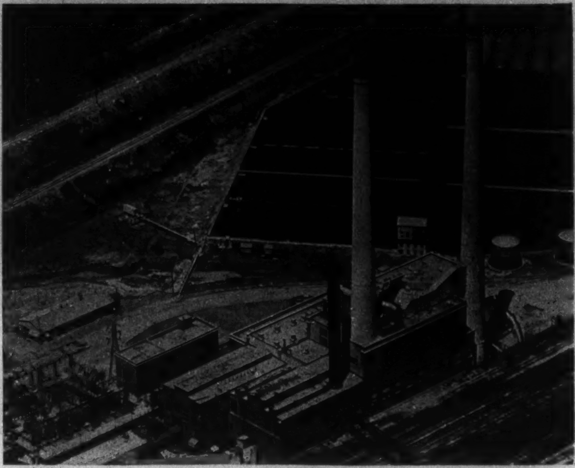
Representatives of the Institute on various bodies were appointed for the administrative year beginning August 1, 1936. L. W. W. Morrow was reappointed a representative on the Engineers' Council for Professional Development for the 3-year term beginning in October 1936.

C. O. Bickelhaupt (chairman, AIEE delegation), F. J. Chesterman, William McClellan, C. E. Stephens, and H. H. Henline (alternate) were reappointed representatives of the Institute on the Assembly of American Engineering Council for the year beginning January 1, 1937; and President A. M. MacCutcheon was appointed a representative on this body for the year beginning August 1, 1936.

The following local honorary secretaries were reappointed for the two-year term beginning August 1, 1936: V. J. F. Brain, for Australia; A. S. Garfield, for France; H. P. Thomas, for India; and W. Elsdon-Dew, for Transvaal.

Vice President C. V. Christie was appointed to represent the Institute at the celebration, in June 1937, of the fiftieth anniversary of The Engineering Institute of Canada.

Other matters were discussed, reference to which may be found in this or future issues of ELECTRICAL ENGINEERING.



The 82,500-kw main generating station of the Dallas (Texas) Power and Light Company, which may be visited by those attending the AIEE South West District meeting to be held in that city, October 26–28, 1936

Future AIEE Meetings

South West District Meeting
Dallas, Texas, Oct. 26–28, 1936

Southern District Meeting
Birmingham, Ala., Dec. 1936

Winter Convention
New York, N. Y., Jan. 25–29, 1937

North Eastern District Meeting
Buffalo, N. Y., May 1937

Summer Convention
Milwaukee, Wis., June 21–25, 1937

Pacific Coast Convention
Spokane, Wash., Date to be determined

Middle Eastern District Meeting
Akron, Ohio, Fall 1937

AIEE Members Invited to Attend Naval Sessions

The Society of Naval Architects and Marine Engineers has invited members of the AIEE to attend the technical sessions of the international meeting of naval architects and marine engineers to be held September 14–19, 1936, under sponsorship of that society. This meeting will be the first of its kind in the United States. The technical sessions will be held September 15–16 at the Waldorf-Astoria Hotel, New York, N. Y.

Naval experts from 8 nations and representatives from the foremost technical marine societies of the world are expected to attend. The technical sessions will begin at 9:30 a.m. on each of the 2 days for which they are scheduled, and will feature problems on safety of life at sea and transatlantic liners.

Summer Convention Sports Winners

Miss Eloise Ferris
Swimming

Miss Jane Dawes
Ping Pong

Pictures of 2 winners of sports events held in connection with the AIEE 1936 summer convention, published on page 928 of the August issue, were incorrectly identified. These 2 winners with correct identification are shown above.

Technical Conferences Held During Summer Convention

Reports of 3 of the 6 technical conferences held during the 1936 A.I.E.E. summer convention at Pasadena, Calif., were published in the August issue. Since then, the following reports of 2 additional conferences have become available.

Carrier Current

By L. F. Fuller

Some 50 persons attended this conference, during which approximately 10 spoke on various phases of their experience with carrier current equipment. First, several speakers gave interesting talks of about 10 minutes each on various phases of the carrier problems in connection with the Boulder Dam-Los Angeles transmission lines. In particular the discussion centered about voice transmission, telemetering, relaying, and voice communication with patrol cars by means of energy radiated from the transmission line to such cars on the patrol road nearby.

During the latter part of the meeting a report was given concerning the performance of carrier current relaying on a portion of the New York (N. Y.) Edison system. The discussion was unusually active and the meeting thoroughly justified itself in every way.

Synchronous Machines

By T. A. Rogers

This conference, which was attended by about 25, began by the showing of some motion pictures illustrating the pulling-into-step phenomena of synchronous machines by A. H. Lauder. Following a brief discussion of the pictures, Mrs. Mabel Macferran Rockwell outlined some of the problems that arose in specifying equipment for the pumping stations along the aqueduct of the Metropolitan Water District of Southern California. Next, C. M. Laffoon discussed the relation of hydrogen cooling to the design and economy of large turbine generators.

Mr. Lauder then outlined briefly the methods used in tensor analysis and the general advantages of the method in systematizing analytical studies of electrical networks and machines. The meeting closed after a brief general discussion.

The conference was a success in bringing together a small group interested in the operation of the synchronous machine although the meeting did not break down into a general round-table discussion, most of those present being interested listeners.

AI & SEE Changes Name. It was announced at a recent meeting of the directors of the Association of Iron and Steel Electrical Engineers that, effective August 1, 1936, the name of the association would be changed to Association of Iron and Steel Engineers. Originally the association was electrical in its membership and discussions. However, as electrifications became more general, the association's activities became closely allied with other engineering branches of the industry. Today, membership is composed of representatives from electrical, mechanical, combustion, lubricating, and welding divisions of the industry, as well as from the executive and operating departments.

RCA Issues "Review." Designated as a "quarterly journal of radio progress," to be published in July, October, January, and April of each year by RCA Institutes Technical Press at 75 Varick Street, New York, N. Y., volume 1, number 1 of *RCA Review* has appeared in the field of technical periodicals under the date of July 1936. The publication is issued under the direction of an imposing board of editors comprising engineers and executives of many RCA divisions.

Graduate Work Offered in Illuminating Engineering

For the past 3 years, The Ohio State University, Columbus, has been experimenting with the development of a practical and effective graduate course in illuminating engineering administered by the department of electrical engineering. In a paper entitled "Successful Results of a Graduate Program in Illuminating Engineering," published in the June 1936 *Transactions* of the Illuminating Engineering Society, Professors F. C. Caldwell (A'94, F'13, member for life) and H. W. Bibber (A'21, M'30) outline the methods of instructions and give details concerning the curriculum.

Concerning the work the authors say in conclusion: ". . . The results secured from experience with this experimental graduate program in illuminating engineering which incorporates a thorough grounding in psychology, physiology, the fine arts, and architecture, as well as the science and art of illumination, have been so successful that it is being continued with only slight modifications."

ASTM Elects Officers. At the recent annual meeting of the American Society for Testing Materials held in Atlantic City, N. J., June 29–July 3, 1936, the following new officers were elected: A. C. Fieldner, chief engineer, Experiment Stations Division, U.S. Bureau of Mines, Washington, D. C., succeeded H. S. Vassar (A'06, M'18) as president; T. G. Delbridge, manager of research and development department, The Atlantic Refining Company, Philadelphia, Pa., was chosen vice president to serve with A. E. White, who became vice president in 1935.

Examination for Army Appointments. An examination of applicants for appointment as second lieutenants, corps of engineers, has been announced by the War Depart-

Membership—

Mr. Institute Member:

The members who have participated in the increase of our membership during the past year have the satisfaction of knowing that the results accomplished have been most gratifying.

The committees about to undertake the membership work can well use the past year's results as a good goal toward which to work during the coming year.

Your continued co-operation is requested to help us meet this objective.

G A Kositzky

Chairman, National Membership Committee

ment. The number of appointments will be limited to 18. Applicants must be male citizens of the United States, who will be between the ages of 21 and 30 on February 1, 1937. Applications for examination must be submitted to the commander of the corps area in which the applicant is resident, in time *to be received* not later than September 15, 1936. The application must be on a special form designated as "War Department Form No. 62," copies of which may be secured from any corps area headquarters, or at any military post or station. Addresses of corps area commanders are as follows: Boston, Mass.; Governors Island, N. Y.; Baltimore, Md.; Atlanta, Ga.; Columbus, Ohio; Chicago, Ill.; Omaha, Neb.; Fort Sam Houston, Texas; and San Francisco, Calif.

Engineering Foundation

Welding Research Subcommittee Meets

The subcommittee on industrial research of the Engineering Foundation welding research committee held a 2-day session, July 23–24, at Watertown Arsenal, Watertown, Mass. Col. G. F. Jenks, commanding officer of the arsenal and chairman of the subcommittee, presided at the various sessions. The AIEE is joint sponsor of the welding research activities of Foundation.

The purpose of the conference was to complete the organization of the subsubcommittees preliminary to the analysis of research activities being conducted to solve the many complicated problems in the welding field. The work was divided among various subsubcommittees including the following material subsubcommittees:

I. Cast iron—(chairman not yet named).
II. Carbon steels—J. C. Hodge, chairman.
III. Low alloy steels—J. H. Critchett, chairman.
IV. High alloy steels—T. H. Nelson, chairman.
V. Aluminum alloys—G. O. Hoglund, chairman.
VI. Copper alloys—D. K. Crampton, chairman.
VII. Nickel alloys—O. B. J. Fraser, chairman.

Three functional subsubcommittees are being organized:

A. Methods of testing—M. F. Sayre, chairman.
B. Analysis of weld failures—(chairman not yet named).
C. Weld stresses—causes and effects—E. Chapman, chairman.

The 2-day session included the presentation of papers and reports on radiography, monel metal, low alloy steels, and high velocity impact tests. Members of the subcommittee had an opportunity to witness various welding operations at the arsenal, the centrifugal casting of low alloy steel, and the testing of metals under impact loads delivered at the rate of more than 300 feet per second.

H. C. Mann, in charge of the work on impact testing, stated that he had found that almost every metal had a critical transition velocity at which its ability to withstand impact loads fell off very sharply. Through the results of these tests the arsenal is able to select those materials that are best suited for the various services encountered in ordnance work.

The Lynn Works of the General Electric Company acted as host to the scientists and engineers and demonstrated the wide applications of welding in the construction of electrical machinery and boilers.

A second conference is planned for the middle of October in Cleveland during the annual convention of the American Welding Society and the Metal Congress Exposition.

C. A. Adams (A'94, F'13, member for life, past-president), chairman of the welding research committee, reported that the Engineering Foundation had made 3 grants totaling $12,000 to launch the project and that leaders of industry had pledged whole-hearted co-operation.

American Engineering Council

Governmental Reorganization

The movement to reorganize governmental agencies instigated some months ago is gaining momentum with 3 investigating committees holding the "ax over Washington," according to the August "News Letter" of AEC. Each committee is moving cautiously and while the president's committee on administrative management is most active among government officials, no hearings are reported to be scheduled prior to November elections. In the meantime, there is much speculation regarding the seriousness of the reorganization intentions and the possibility that overlapping responsibilities may result in frustration of purpose.

Although similar studies in the past have each left their train of broken promises, false hopes for retrenchment, futile congressional investigations, and ineffectual recommendations, the field never seemed so ripe for reorganization and economy measures. Entering many new activities, the federal government has piled 40 new agencies on top of an already top-heavy administrative structure. Civil Service reports an increase of more than 250,000 civilian employees since February 1933. Unofficial figures show the federal payroll for June 1936, was $326,159,486 for 4,664,732 employees. That is an obligation of about $2.65 per month against every man, woman, and child in the United States.

On the receiving end, it is estimated that 16,314,248 people have already received benefits from the emergency agencies. Emergency funds have gone into every state and territory, and congressional appropriations for that purpose run into many billions with approximately $9,487,163,446 in a single session. The public debt at the close of the fiscal year for 1936 was approximately $33,779,000 and the total revenue for the 1936 fiscal year fell about $4,764,000 short of the total expenditures.

The proportions of the task ahead of the "reorganization committees" are difficult to visualize, but an idea may be gotten from reports that duplications in service and overlapping functions between old and new bureaus have reached a point where there are as many as 23 agencies dealing seriously with a single problem. Such knowledge is said to have been in possession of Senator Byrd when he succeeded in getting the Senate resolution authorizing the investigation to read that the Senate Investigation Committee should sit, not only in the next, but in "succeeding Congresses."

Regardless of past experience and political implication, the Byrd resolution with a continuing authority to bring administrative inefficiencies to the surface stands without handicap except for limitation of funds, until repealed by an act of Congress.

Upstream Engineering Conference

In reply to the many inquiries received by AEC regarding the objectives of the Upstream Engineering Conference, Dr. H. S. Person, acting for the organizing committee of the Upstream Engineering Conference has made the following statement available:

> "The Upstream Engineering Conference, to be held in Washington, D. C., September 22 and 23, has as its general objective continuation of public attention on the serious problem of conservation related to "upstream engineering," and as its special objective emphasis on the engineering aspects of the problem—a co-ordination of our engineering knowledge concerning precipitation, infiltration, ground-water, runoff, small streams, and other small surface waters.
>
> "Publications of the past year have already impressed upon the public the seriousness of the problem of conserving soil and water, and have indicated a relationship between these 2 phases of the problem. With that background it is now time to emphasize the engineering aspect—on the one hand to interest engineers in this problem as a field of future professional activity, and on the other hand to head off sporadic efforts at conservation and regulation by laymen who do not perceive the engineering basis of conservation.
>
> "There has been no proposal to formulate at the conference itself a specific program of action or to formulate the details of an engineering technique for work in headwater areas. As one member of the committee has put it: 'The purpose of this conference is not to reach any conclusions, but to direct attention to a neglected area and to secure for the engineering that may be undertaken some measure of public support.' There is, however, the objective of bringing together in a compact body of proceedings the various engineering elements of the problem now widely scattered through engineering and other literature.
>
> "The tentative program does provide a closing session on 'organization for action.' The purpose of this session is to provide an open forum for a comprehensive and well-balanced discussion of all points of view toward organization for conservation of soil and water resources in headwater areas.
>
> "The completed program of the Upstream Engineering Conference will be released shortly. The

speakers and discussers have been drawn primarily from among those engineers who have had actual field experience in the control of headwaters.

"The response of the engineering, scientific, agricultural, and industrial professions has been noteworthy. Over 50 prominent national societies and agencies—private and public organizations—have indicated their willingness to be listed as 'co-operating agencies,' and of those, a good proportion have offered suggestions, lists of members, and material to be included in the official record of the conference. Acceptances for the general committee, likewise, indicate a wide and active interest in the conference.

"The organizing committee has been officially notified that the French government is sending a prominent delegate to the World Power Conference with instructions to remain for the Upstream Engineering Conference and address those attending the dinner scheduled for the evening of September 22. This delegate will be one who has had experience with control of headwaters—Alpine and others—and in the solution of many vexing soil and water conservation problems in France. Major General Edward M. Markham and Professor Aldo Leopold have accepted the committee's invitation to deliver addresses on the subjects indicated in the preliminary announcement.

"In order to acquaint the younger members of the American community with the problems of headwater regions, a supplementary conference will be held on September 24. Those attending will be young engineers and other prospective leaders, of ages ranging between 20 and 30. They will be drawn from all parts of the country through the enthusiastic co-operation of engineering schools and various national organizations. Some of these agencies, realizing the importance of the conference, are financially obligating themselves to bring this younger element to Washington and furnish them with accommodations. The majority of these young men will undoubtedly also listen in at the preceding 2 days of engineering sessions."

Who's Who in Engineering

At the request of the Lewis Historical Publishing Company of New York, N. Y., publishers of the 3 earlier editions of "Who's Who in Engineering," a sponsoring committee for the fourth edition has been appointed by President A. A. Potter of AEC. Because of his previous service on similar committees, President Potter has been prevailed upon to act as chairman with the following members: A. W. Berresford (A'94, F'14, past-president), D. S. Kimball, C. F. Scott (A'92, F'25, HM'29, past-president), G. T. Seabury, C. E. Davies, H. H. Henline (A'19, M'26, national secretary), A. B. Parsons, J. F. Coleman, and F. M. Feiker (M'34).

It is anticipated that the questionnaires outlining the qualifications for inclusion in the new edition will be mailed to members of the profession early in the fall. Engineers eligible for this new edition will be listed without obligation. The new edition will be published in the spring of 1937 and may be purchased for $10 per copy.

Third World Power Conference

The engineering profession is honored by having one of its best known members chosen as chairman of the Third World Power Conference meetings. Dr. William Durand, professor emeritus of mechanical engineering at Leland Stanford University, Palo Alto, Calif., will serve in that capacity. Since he is also a linguist, he will make his address of welcome in English, French, German, and Spanish.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Professional Aspects of Engineering Education

To the Editor:

Your issue of August 1936 carries a review of the article "Professional Aspects of Engineering Education" which appeared under the authorship of Andrew Fraser, Jr., in the *Monthly Labor Review*, published by the United States Department of Labor. It is entirely proper that this review should have been published in the various technical and professional engineering journals, for the study of the engineering profession on which it was based promised to be—in fact, this first installment of the results of the survey shows clearly that it is—a very significant contribution to our knowledge of the circumstances and the education of the personnel of the profession. No such comprehensive study, as to numbers canvassed, has been attempted previously so far as I know. The results of this survey will be quoted widely as an authentic and accurate picture of those phases of the profession that the assembled data cover. It is highly important, therefore, not only that the original data be representative of the bulk of the profession and of its several divisions, but that the analysis and interpretation of the data be accurate.

It is for this reason that I am venturing to call attention to a particular phase of the analysis and interpretation as given by Mr. Fraser in the article mentioned. The following statement is there made: "Graduate study in engineering does not appear to be of any considerable importance as a prerequisite to practice in the engineering field." This is followed by a summary of proportions of graduates in the principal professional divisions who hold master's degrees. Presumably these ratios are based upon analysis of returns from all groups reporting, regardless of age or duration of period since graduation from college.

It happens that for the past 2 years a comprehensive survey of the status of graduate work in American engineering colleges has been in progress under the joint direction of a committee of the Society for the Promotion of Engineering Education and the United States Office of Education. Part of the results of this survey appeared in an article "Graduate Study," in the *Journal of Engineering Education*, volume 26, number 4, December 1935, pages 313–55. A final, comprehensive report is now in the hands of the public printer. One purpose of this survey was to learn the trends of graduate work in engineering in recent years. The results indicate a very rapid growth during the past 15 years, as the following tabulation indicates:

Academic Years	Total Number of Students Enrolled in Graduate Work in Engineering (U.S.A.)	Total Number of Advanced Degrees in Engineering Conferred
1921–22	368	178
1925–26	1,014	267
1930–31	2,939	418
1931–32	3,961*	1,002
1933–34	2,756*	1,197

* The apparent shrinkage in enrollment from 1931–32 to 1933–34 is due to the fact that up to and including 1931–32, when the statistics were compiled by the Office of Education all graduate students enrolled in engineering colleges, schools, and departments were counted. Since some of the separately organized colleges of engineering and some of the schools of engineering of universities reported students enrolled in them in such curricula as chemistry, physics, architecture, and the like, the figures were inflated prior to 1933–34. For that year, however, the figures are accurate. All American engineering institutions offering graduate courses are included in them.

The tabulation and other data gathered in the survey, indicate a very rapid growth in graduate study. In enrollments there was a gain of nearly 8-fold between 1921–22 and 1933–34, while in number of graduates of advanced courses the gain was nearly 7-fold in the same period. At the present time the number of graduate students of engineering is roughly 1/4 the number of bachelor's degrees conferred in that year. If the data that the SPEE committee has been able to secure from other than its own questionnaires is reliable as to other professions, it appears that engineering ranks second only to chemistry in the number of doctor's degrees conferred annually in the various divisions of the physical sciences. It is impossible to learn where it stands in relation to other fields in the proportion and number of master's degrees conferred, although the rank of engineering is undoubtedly very high in the list.

It seems proper, therefore, to question whether it is correct to infer from the data obtained in the Labor Department's study that graduate work in engineering is of relatively little importance, at present, as a prerequisite to practice. The fault in this interpretation appears to lie in the fact that the analysis was based upon the entire group of engineers canvassed, regardless of age. Such an analysis would assume the conditions in the engineering profession to be static, so far as education and training are concerned. It is evident from the trends indicated by the SPEE-Office of Education study, and as well informed engineering educators know, that the trend toward graduate work in engineering education has been a strong one in recent years;

it is also clear that industry and the profession at large are beginning to look upon graduate work—in fact, some divisions of the profession already have come to look upon it—as a highly desirable preparation for certain types of positions and for certain fields of work. The attitude of the profession toward the preparation of its recruits seems to be undergoing a change in that greater weight is being given not only to sounder training in the fundamentals of engineering science, but also to more extended training in its higher phases.

The foregoing discussion of the results of the Labor Department's study is given not only because of its bearing upon a matter of graduate work alone, but also because of the same condition, namely, changes of conditions in the profession as represented by differences of results of studies when different age groups are analyzed, may affect other aspects of this or similar investigations. It may be hoped that the Labor Department could amplify its results in terms of studies of the several age groups among those who supplied information.

Very truly yours,

H. P. Hammond

Chairman, Committee on Graduate Study,
Society for the Promotion of
Engineering Education

Voltage Regulation of Alternators

To the Editor:

In a letter in the April 1936 issue of Electrical Engineering (pages 424–5) Prof. Reed raised the question of the relative merits of 2 methods of determining the regulation of synchronous machines. These methods he has referred to as the "general" method and the "A.I.E.E." method. Prompted by Prof. Reed's letter I am submitting the following constructions which show clearly the difference in the 2 methods. The effect of armature resistance has been omitted, but may be included by obvious alterations.

In figure 1 is shown the vector diagram for a synchronous machine. This is the diagram usually given in text books. The vector *oa* represents the terminal voltage and *ac* the Potier reactance drop. The vector *oc* may be thought of as being generated by the flux ϕ, 90 degrees in advance. The excitation corresponding to this flux is *od* and is taken from the no load saturation curve for the voltage *oc*. To this excitation must be added the field current required to overcome the demagnetizing effect of the armature current. Now the triangle *ode* can be rotated backward 90 degrees around the origin and forms the triangle *ogh*. The total excitation for the "general" method is then *oh*.

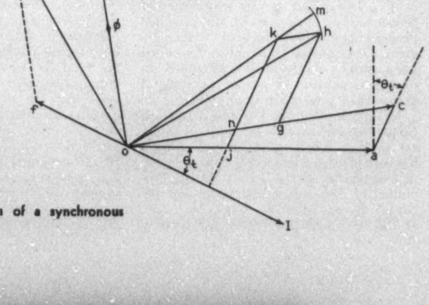


Fig. 1. Vector diagram of a synchronous machine

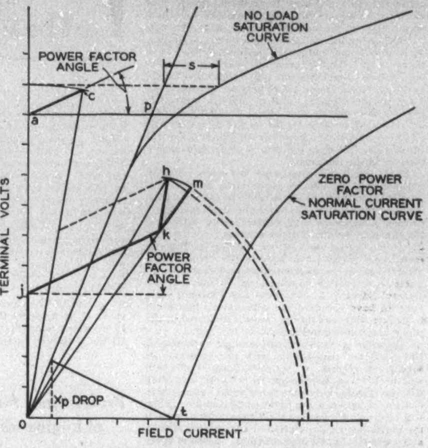


Fig. 2. Determination of load field current

ac = x_p drop
oj = *ap* on air gap line
jk = *ot* on zero power factor curve
kh = *km* = saturation factor *s*
om = excitation by A.I.E.E. method
oh = excitation by "general" method

The A.I.E.E. method, that recommended by the American Standards Association, consists in first laying off along *oa* the excitation, *oj*, corresponding to the terminal voltage measured on the air gap line. Next lay off *jk*, which is equal to the field current for full load zero terminal voltage from the zero power factor saturation curve. A saturation factor, *s*, is next obtained by constructing the internal voltage *oc* as before and reading for this voltage the difference in excitation between the actual no load saturation curve and the air gap line. The distance *s* is laid off along the line *ok*, extended, giving the distance *om* as the excitation.

It may be observed that *gh* represents the excitation required to overcome the demagnetizing action of the armature current as taken from the base of the Potier triangle, but that *jk* represents the total base of the Potier triangle. It can also be seen that *jn* represents the excitation necessary to develop the Potier reactance drop. It follows then that *nk* is equal to *hg*, and since *gh* and *jk* are parallel that *kh* is equal to *ng*. But, referring to the no-load saturation curve, *ng* is equal to *s*; it follows that *kh* is equal to *km*.

The only difference between the 2 methods consists in the manner in which saturation is taken into consideration. In the A.S.A. method *s* is measured from *k* along the line *ok* whereas in the "general" method *s* is measured from *k* along a line parallel to *oc*. The A.S.A. method gives an excitation slightly greater than the "general" method, but the difference is insignificant; in fact, this difference is masked entirely by the accuracy to which x_p can be determined. One can hardly say that one method is superior to the other in result. Neither can one say that the "general" method is more rational or exact, or more readily applied. It is fundamentally based upon x_p which is determined somewhat arbitrarily and is not subject to exact measurements. The proper value of x_p, which when used in the methods outlined gives the correct values of excitation, is dependent upon the relative amounts of saturation in the stator and rotor. This question has been given considerable attention before the A.I.E.E. within the past few years. A discussion by L. A. Kilgore (Electrical Engineering, October 1935, pages 1117–18) is particularly pertinent.

Very truly yours,

Chas. F. Wagner (A'20, M'27)

Research Engineer,
Westinghouse Elec. & Mfg. Co.,
E. Pittsburgh, Pa.

Revised Sphere-Gap Spark-Over Voltages

To the Editor:

As one of the many who contributed to AIEE Standard No. 4, I was very much interested in the tables of revised sphere-gap spark-over voltages published on page 783 of Electrical Engineering for July. In attempting to compare the new values with the old through the medium of curves, I discovered that the new kilovolt values are in crest instead of sinusoidal rms terms, although I could find no accompanying statement to that effect. While there is much to be said in favor of this change, it should be kept in mind that AIEE standards are based upon a sine wave of voltage and stated in rms terms. Also, it is the rms value that is ordinarily available for measurement purposes.

Very truly yours,

C. T. Weller (A'20, M'21)

General Engineering Laboratory,
General Electric Company,
Schenectady, N. Y.

Editor's Note: See subcommittee's supplementary statement on page 950, this issue.

Personal Items

Francis Ellis Johnson (A'13, M'26, F'31) dean of the college of engineering, University of Missouri, Columbia, has been elected a director of the Institute, by the board of directors on August 4, 1936, as successor to the late George Carl Shaad, for the remainder of the term ending July 1, 1939. Dean Johnson was born May 27, 1885, at Le Roy, Mich., and received the degrees of bachelor of arts (1906) and electrical engineer (1909) at the University of Wisconsin. Following a brief service with the Seattle-Tacoma Power Company, Seattle, Wash., he entered the employ of the British Columbia Electric Railway Company and the Vancouver (B. C.) Power Company as a foreman on substation construction and repair, where he remained until he accepted an instructor's appointment to the electrical engineeing faculty of Rice Institute, Houston, Texas, in 1912. Dean Johnson was appointed instructor in electrical engineering at the University of Kansas in 1915, and became successively assistant professor, associate professor, and professor of electrical engineering. In 1928 he was appointed head of the department of electrical engineering; however, he resigned in the same year to become head of the department of electrical engineering at Iowa State College, Ames. He has held his present position since 1935, and in addition to his teaching duties, has served as a consulting engineer for several electrical manufacturing and utility companies. Dean Johnson served as a member of the Institute's committee on education, 1933–35. He is a member of the Society for the Promotion of Engineering Education, Tau Beta Pi, Eta Kappa Nu, and Sigma Xi.

T. J. Killian (A'35) vice president and director of research, Barkon Tube Lighting Corporation, Seattle, Wash., has been awarded the 1935 AIEE North West District prize for initial paper for his paper "Gaseous Discharge Lamps Having External Electrodes." Doctor Killian was born at Schenectady, N. Y., in 1905, and received the degrees of bachelor of science in electrical engineering (1925) and master of science in electrical engineering (1926) at the Massachusetts Institute of Technology; in 1927 he received the degree of master of arts and in 1929 that of doctor of philosophy at Princeton University. In 1929 he was appointed instructor in electrical engineering and physics at Massachusetts Institute of Technology, and in 1932 became director of research of the Luminous Tube Lighting Corporation, Seattle. Recently the Luminous Tube Lighting Corporation was reorganized under the name of Barkon Tube Lighting Corporation, with Doctor Killian as vice president and director of research. Since 1935 he has served also as dean of mathematics at Seattle College. He is a member of the American Physical Society, Optical Society of America, and Illuminating Engineering Society.

T. A. Rogers (A'31) instructor in electrical engineering, University of California, Berkeley, has been awarded the 1935 AIEE Pacific District prize for initial paper for his paper "Test Values of Armature Leakage Reactance." Doctor Rogers was born June 29, 1905, at Mountain View, Calif., and received the degrees of bachelor of science (1928), master of science (1930), electrical engineer (1933), and doctor of philosphy (1935) at the University of California. After one year of graduate study, he was appointed to the electrical engineering staff of the University of California as a laboratory assistant, and in 1933 was promoted to the rank of instructor. He is a member of Tau Beta Pi, Eta Kappa Nu, and Sigma Xi.

J. L. Harvey (A'25) superintendent of power control, New York Power and Light Corporation, Albany, with H. D. Braley (A'18) co-author of the paper "Fault and Out-of-Step Protection of Lines," has been awarded the 1935 AIEE North Eastern District prize for best paper. Mr. Harvey was born at Chartley, Mass., in 1889, and was graduated from Worcester Polytechnic Institute. In 1910 he was employed as a switchboard engineer for the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., and remained in that position until 1913, when he became system operator of the Duquesne Light Company, Pittsburgh, Pa. Following a 2 year association with Stone and Webster, Inc., Boston, Mass., he served as a designer of submarine signaling devices in the U. S. Naval Experiment Station, New London, Conn., during 1918–19. After spending a year in industrial electrical design work, Mr. Harvey returned to the Stone and Webster Company during 1920–22, and in 1922 he accepted a position as operating engineer for the Adirondack Power and Light Corporation, Schenectady, N. Y. He has been with the New York Power and Light Corporation since 1927.

Frederick Bedell (A'91, F'26, and member for life) formerly professor of physics, Cornell University, Ithaca, N. Y., has resigned to accept a position with the R. C. Burt Scientific Laboratories, Pasadena, Calif. Doctor Bedell was born at Brooklyn, N. Y., in 1868, and received the degrees of bachelor of arts (1890) at Yale University and doctor of philosophy (1892) at Cornell University. In 1892 he was appointed instructor in the department of physics of Cornell University; in 1893, assistant professor of physics, and in 1904, professor of physics. He has contributed his services liberally to the Institute, having been manager, 1914–16; vice president, 1917–18; and a member of many of its technical committees. Doctor Bedell is the author of a great many papers presented before the Institute, and of various technical books and physical papers; he was associate editor of *The Physical Review*, 1894–1913, and managing editor, 1913–22. He is a member of several technical societies, including the American Academy of Arts and Sciences, American Physical Society, Optical Society of America, Phi Beta Kappa, Eta Kappa Nu, and Sigma Xi.

R. M. Morton (A'35) Vancouver, B. C., Canada, has been awarded the 1935 AIEE Canada District prize for initial paper for his paper "Torque in a Bipolar Induction Meter." Mr. Morton was born at Barmouth, North Wales, in 1902, and is an electrical engineering graduate (1925) of the University of British Columbia. Following his graduation, he was employed in the test department of the Canadian General Electric Company, Peterboro, Ont., and was transferred to the switchboard engineering department in 1926. Mr. Morton left the Canadian General Electric Company in 1928, to join the British Colum-

T. A. ROGERS

J. L. HARVEY

T. J. KILLIAN

F. E. JOHNSON

E. S. CORNELL

R. M. MORTON

ABE TILLES

H. D. BRALEY

bia Electric Railway Company, Ltd., Vancouver, where he became engaged in short circuit studies and relay development work. His affiliation with that company terminated in 1931, and he has not been directly connected with engineering work since that time.

H. D. Braley (A'18) division engineer, The New York (N. Y.) Edison Company, with J. L. Harvey (A'25) co-author of the paper "Fault and Out-of-Step Protection of Lines," has been awarded the 1935 AIEE North Eastern District prize for best paper. Mr. Braley was born at Virden, Ill., in 1886, and was graduated in electrical engineering from the University of Illinois in 1909. Following his graduation, he entered the employ of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., as an engineering apprentice; in 1911 he was transferred to the design section of that company as a transformer engineer. In 1917 Mr. Braley was commissioned to the development of electrical equipment with applications to the electrochemical industry, and in 1919 was transferred to the Westinghouse Lamp Company, Bloomfield, N. J., to undertake development of electron tube equipment. He accepted a position as electrical engineer for The New York Edison Company in 1921, where his work has included relay protection and station design and operation, and his association with that company has since been continuous.

A. W. Dater (A'23) formerly president of the Stamford (Conn.) Gas and Electric Company, recently was elected vice chairman of the board of directors of the Connecticut Power Company, as a result of the consolidation of the Stamford Gas and Electric Company with the Connecticut Power Company. Mr. Dater was born at Brooklyn, N. Y., in 1872, and received the degree of bachelor of philosophy at the Sheffield Scientific School of Yale University in 1895. Following his graduation, he joined the motive power department of the Pennsylvania Railroad Company, where he remained until 1897; he served briefly as assistant general superintendent of the Kings County Electric Light and Power Company of Brooklyn, N. Y., before becoming treasurer of the Edison Electric Illuminating Company, Brooklyn, N. Y., in 1898. In 1904 Mr. Dater became associated with the Stamford Gas and Electric Company as treasurer; he became vice president and general manager in 1911, and president in 1917.

Abe Tilles (A'30) electrical engineering instructor, University of California, Berkeley, has been awarded the 1935 AIEE Pacific District prize for best paper for his paper "Spark Lag of the Sphere Gap." Mr. Tilles is a native (1907) of New York, N. Y., and received the degrees of bachelor of science in electrical engineering and bachelor of science in mechanical engineering at the University of California in 1928. Following his graduation, he was employed as an electrical tester in the research laboratories of the Department of Water and Power of the City of Los Angeles, Calif., where he remained until appointed teaching associate in electrical engineering at the University of California in 1930, becoming instructor in 1933. During the past year, he has done electrical planning and design work for the frequency change section of the Bureau of Power and Light, City of Los Angeles, Calif. Mr. Tilles was awarded the degrees of master of science and doctor of philosophy in 1932 and 1934, respectively, by the University of California. He is the newly appointed counselor of the AIEE University of California Branch, and is a member of Eta Kappa Nu and Sigma Xi.

F. L. Boissonnault (A'18, M'26) formerly a control engineer for the Westinghouse Electric and Manufacturing Company, San Francisco, Calif., recently was appointed electrical engineer for the Department of Water and Power of the City of Los Angeles. Mr. Boissonnault is a native (1889) of Spokane, Wash., and an electrical engineering graduate of the University of Washington. After serving the Puget Sound International Railway and Power Company as foreman in charge of the electric meter and trouble department, 1912–17, he was employed in the testing department of the Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pa., and was transferred to the San Francisco offices as a control engineer in 1918.

E. S. Cornell (A'28) formerly assistant chief engineer, Delta-Star Electric Company, Chicago, Ill., has been appointed chief engineer. Mr. Cornell is a native (1900) of Oslo, Norway, and received his formal technical education at the University of Zurich in Switzerland. After serving briefly as a draftsman for the Oslo Electric Light and Power Company during 1923–24, he came to the United States and was employed by the Ohio Power Company, first as an electrician and later as assistant electrical engineer. In 1925 Mr. Cornell joined the engineering staff of Sargent and Lundy, Chicago, as a power and substation designer, which position he held until he joined the Delta-Star Electric Company in 1926 as an assistant engineer. He was appointed assistant chief engineer in 1934.

D. W. Pugsley (A'36) radio engineer, radio receiver engineering design department, General Electric Company, Bridgeport, Conn., with R. J. Biele (A'36) co-author of the paper "Some Polarity Characteristics of Sphere Gap Sparkover," has received the 1935 AIEE North West District prize for Branch paper. Mr. Pugsley is a native (1912) of Salt Lake City, Utah, and received the degree of bachelor of science in electrical engineering at the University of Utah in 1935. He has been employed by the General Electric Company since his graduation. He is a member of Tau Beta Pi.

F. O. McMillan (A'14, F'32) research professor of electrical engineering, Oregon State College, Corvallis, has been appointed to serve as an alternate representative of the Institute on the American Standards Association sectional committee on radio-electrical co-ordination. Professor McMillan has been a member of the Institute's committees on student Branches (1930–36), electrophysics (1934–36), and research (1934–36), and in addition, was a vice president, 1935–36. He is the author of several papers presented before the Institute.

R. J. Biele (A'36) radio engineer, radio receiver test engineering department, General Electric Company, Bridgeport, Conn., with D. W. Pugsley (A'36) co-author of the paper "Some Polarity Characteristics of Sphere Gap Sparkover," has received the 1935 AIEE North West District prize for Branch paper. Mr. Biele was born January 31, 1914, at Salt Lake City, Utah, and received the degree of bachelor of science in electrical engineering at the University of Utah in 1935. He has been associated with the General Electric Company since his graduation.

J. H. Blankenbuehler (A'31) design engineer, motor engineering department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., recently was awarded the "Westinghouse order of merit" for "design and engineering application in connection with welding generators; for the energy and skill which enabled him to improve substantially their operation and appearance." Mr. Blankenbuehler, an electrical engineering graduate of Lehigh University, has been employed by the Westinghouse Company continuously since his graduation in 1923.

F. B. Jewett (A'03, F'12, and past-president) president, Bell Telephone Laboratories, Inc., and vice president, American Telephone and Telegraph Company, New York, N. Y., recently was awarded the honorary degree of doctor of science by Harvard University, with the citation, "The creator of a famous laboratory whence came miracles of modern telephony, an engineer who points the way for industry to follow."

O. H. Eschholz (A'20) manager of the patent department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., recently was awarded the "Westinghouse order of merit" for "marked ability and energy in his departmental management, particularly in a period of general depression; for excellence of record in the disposition of patent cases; for commercial insight in the negotiation of patent licenses; for general efficiency in the prosecution of unavoidable patent litigation." Mr. Eschholz has served the Westinghouse Company since 1910.

Alex Dow (A'93, F'13, and member for life) president, Detroit (Mich.) Edison Company, recently was elected a trustee of the Rackham Engineering Foundation. An item regarding the incorporation of the Rackham Engineering Foundation appeared in the August 1936 issue of Electrical Engineering, page 937, and a biographical sketch of Mr. Dow was included in the July 1936 issue, page 846.

W. G. Kelley (A'08, F'26) plant design engineer, Commonwealth Edison Company, Chicago, Ill., has been elected to serve as first vice chairman of the American Society for Testing Materials committee *A*-5 on corrosion of iron and steel. Mr. Kelley served on the Institute's committee on power transmission and distribution, 1924–25.

B. D. Horton (A'14) president, Square D Company, Detroit, Mich., recently was elected a trustee of the Rackham Engineering Foundation. A brief item regarding the establishment of the Rackham Engineering Foundation appeared in Electrical Engineering for August 1936, page 937.

D. L. Curtner (A'14, M'28) associate professor of electrical engineering, Purdue University, Lafayette, Ind., has been appointed to serve as an alternate representative of the Institute on the American Standards Association sectional committee on transformers.

E. R. Love (A'35) formerly a demonstrator in the electrical laboratories, University of Manitoba, Winnipeg, Canada, has become a graduate apprentice for the Canadian Westinghouse Company, Ltd., Hamilton, Ont.

R. W. Warner (M'28) professor of electrical engineering, University of Kansas, Lawrence, has been appointed to serve as the Institute's representative on the American Standards Association sectional committee on radio-electrical co-ordination.

S. B. Farnham (A'36) formerly a student engineer in the testing department, General Electric Company, Schenectady, N. Y., has been transferred to the Philadelphia, Pa., works of that company.

W. W. Brooks (A'34) formerly electrical engineering research assistant, University of Illinois, Urbana, now is employed by the General Electric Company, Erie, Pa.

E. T. Lentz (A'33) former draftsman, Ohio Bell Telephone Company, Toledo, has been transferred to the Dayton offices of that company as supervisor of records.

R. E. Roesch (A'25) formerly division manager, Virginia Public Service Company, Harrisonburg, has been transferred to the Alexandria offices as division manager.

Meyer Ziev (A'34) recently accepted a position as junior blueprint and photostat operator at the U.S. Navy Yard, Brooklyn, N. Y.

W. L. Bryant, Jr. (A'28) now is employed by the astrophysics department of the California Institute of Technology, Pasadena.

R. H. Grant (A'31) now is employed in the material laboratory of the U.S. Navy Yard, Brooklyn, N. Y., as a junior materials engineer.

F. V. Gardner (A'34) now is employed by the Los Angeles (Calif.) Bureau of Power and Light, as a junior electrical engineer.

T. L. Botterill (A'35) recently accepted a position with the Pullman Company, Denver, Colo.

B. T. Anderson (A'34) has accepted a position as electrician for the Dietz Electric Company, Elkhart, Ind.

L. F. Anderson (A'33) recently accepted a position as engineer for the Wabash Appliance Corporation, Brooklyn, N. Y.

B. E. Heard (A'35) Boulder, Colo., recently accepted a position with The Geotechnical Corporation, Dallas, Texas.

H. F. Bouquin (A'36) now is connected with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

H. A. Steindorf (A'26) now is connected with the Virginia Alberene Corporation, Schuyler.

C. W. Methfessel (A'26) now is employed in the Youngstown division distribution office of the Ohio Edison Company.

A. V. Carr (A'26) now is employed by the Hercules Powder Company, Wilmington, Del.

Obituary

Edward Weston (A'84, M'84, HM'33, Lamme medalist '32, past-president, member for life) chairman of the board of the Weston Electrical Instrument Corporation, Newark, N. J., died August 20, 1936. Doctor Weston was born at Brynn Castle, near Oswestry, Shropshire, England, May 9, 1850, and received his formal education in that country. From boyhood he manifested a keen interest in electrical and mechanical investigations. Coming to the United States in 1870, he was employed by William H. Murdock and Company, New York, N. Y., manufacturers of photographic chemicals, and in the following year entered the employ of the American Nickel Plating Company. In 1872 Doctor Weston established his own electroplating business, and during the following 2 years made several improvements in dynamos for electroplating, including a voltage regulation system. In 1874 he became a partner of the firm of Stevens, Roberts, and Havell, Newark, for the manufacture of dynamo-electric machines. The business of that firm was incorporated under the name of the Weston Dynamo Electric Machine Company in 1877, and in 1881 was consolidated with the United States Electric Light Company, of which Doctor Weston served as electrician until 1888. While in that position he received many patents on dynamo construction, and made extensive investigations in the field of lighting; however, he encountered difficulties in all his researches in making the necessary electrical measurements with the instruments available at that time. As a result, he designed and built for his own experiments a set of more practical instruments. They were so successful that he relinquished his other interests in 1888 to devote his entire time to the development of more convenient and more accurate instruments. At that time he established the Weston Electrical Instrument Corporation, of which he was vice president and general manager from 1888 until 1905, and president from 1905 to 1924, when he became chairman of the board. His achievements in developing instruments of high speed, accuracy, and portability are well known. He undertook to improve the Clark-Carhart cell, which had been adopted in 1893 as an international standard, and the result of his research was the Weston cadmium cell, which in 1908 was adopted by the International Electrotechnical Commission as the official standard of electromotive force. In addition to being a charter member of the Institute, Doctor Weston was a member of its first board of directors and served as manager, 1884–87. Following his term as president (1888–89) he was vice president, 1889–91. He received the honorary degrees of doctor of laws from McGill University (1903) and doctor of science from Stevens Institute of Technology (1904) and Princeton University (1910). In 1932 the Lamme Medal was awarded to Doctor Weston "for his achievements in the development of electrical apparatus, especially in connection with precision measuring instruments." He was a member of many engineering and scientific societies.

William Arthur Hillebrand (A'08, M'13) professor of electrical engineering, University of California, Berkeley, and chairman-elect of the San Francisco Section, died July 24, 1936. Professor Hillebrand was born October 9, 1882, at Perrysburg, Ohio, and received the degree of bachelor of arts at Cornell University in 1905. Following his graduation, he attended Stanford University for one year as an electrical engineering student, and, in 1907, served in the Pacific Coast office of the Western Electric Company. In the same year he was appointed an instructor on the electrical engineering faculty of Stanford University; in 1910 he was appointed assistant professor of electrical engineering. In 1911 Professor Hillebrand became professor of electrical engineering and executive head of the electrical engineering department at the Oregon State Agricultural College, Corvallis, where he remained until 1914, when he accepted a position as electrical engineer in the office of electrical distribution of the Pacific Gas and Electric Company, San Francisco, Calif. In 1918 he became engaged in the manufacture of arc radio transmitters with the Federal Telegraph Company, Palo Alto, Calif., and in 1919 was appointed commercial engineer for the Ohio Brass Company, with offices in San Francisco. Professor Hillebrand spent a year in Japan as a representative of the Ohio Brass Company, and, upon his return, was transferred to the Barberton, Ohio, offices of that company. In 1932 he left the employ of the Ohio Brass Company to assume his professorship of electrical engineering at the University of California. He was a member of the Institute's committee on power transmission and distribution, 1925–26 and 1933–36, counselor of the University of California student Branch, 1933–36, and recently was co-author of a paper presented before the Institute.

John A. Rockwood (A'29) valuation engineer, Portland (Ore.) General Electric Company, died July 4, 1936. Mr. Rockwood was born August 16, 1876, at Rensselaer Falls, N. Y., and received the degree of bachelor of arts at Amherst College in 1896. During 1906–07 he was a rodman for the Southern Pacific Railway Company, and in 1907 served as instrument man for W. S. Barstow and Company during the construction of the lines of the Oregon Electric Railway Company. Following the completion of this system, Mr. Rockwood was retained by W. S. Barstow and Company, as estimator and assistant superintendent of construction, until he joined the engineering staff of the Portland Electric Power Company in 1911; during the period 1920–30 he served that company as valuation engineer. He became associated with the Portland General Electric Company as valuation engineer in 1930, and, except for a brief affiliation (1931) with the Pacific Northwest Public Service Company, served that company continuously.

Carroll Thomas (A'05) electrical engineer, United Railway and Electric Company, Baltimore, Md., died June 10, 1936. Mr. Thomas was born October 13, 1871, in St. Mary's County, Ind., and was a graduate (1889) of the Polytechnic School of Baltimore. In 1890 he was employed as a machinist and armature winder for the Baxter Motor Works, Baltimore, and during the period 1892–98 served in the engineering department of the Central Railway Company, Baltimore, as a controller inspector. In 1898 the Central Railway Company merged with the City Passenger Railway Company under the name of the latter company, and Mr. Thomas was retained in the engineering department of the new company. In 1899 the street railways of Baltimore were consolidated under the name of The United Railways and Electric Company, and Mr. Thomas was appointed assistant to the chief engineer of power houses. In 1906 he was designated as electrical engineer, and held that position continuously for almost 30 years.

Russell Armstrong Yerxa (A'08, M'26) electrical construction superintendent, Dwight P. Robinson and Company, Philadelphia, Pa., died December 12, 1935, according to word just received at Institute headquarters. Mr. Yerxa was born June 15, 1882, at Minneapolis, Minn., and acquired his technical education through home study. In 1900 he was employed by Stone and Webster, Boston, Mass., as electrical construction foreman, in which capacity he had a part in many of that company's construction projects during the following 20 years. In 1920 Mr. Yerxa accepted a similar position with Dwight P. Robinson and Company, and served in both the New York, N. Y., and Philadelphia offices of that company.

John A. Sirnit (A'15, M'18) designing engineer, Alabama Power Company, Birmingham, died June 29, 1936. Mr. Sirnit was born May 5, 1881, at Roemershof, Russia, and received his technical education by serving an apprenticeship in Germany. In 1905 he entered the employ of Allgemeine Electricitaets Gesellschaft, Riga, Russia, as an electrical designer and later (1906) served briefly as assistant superintendent of works. In 1907 Mr. Sirnit came to the United States and joined the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., as an electrical designer, in which capacity he remained until he accepted a position with the Alabama Power Company in 1912.

Hugo Vecera (A'22) district foreman, motive power department, Interborough Rapid Transit Company, New York, N. Y., died June 25, 1936. Mr. Vecera was born December 17, 1881, at Vienna, Austria, and received his technical education through home study. After being engaged in electrical maintenance work for several years, he was employed by the Interborough Rapid Transit Company as a converter tender in 1912. His service with that company was continuous, and he served successively as substation operator, substation foreman, substation district foreman, and district foreman in the motive power department.

Membership

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before Sept. 30, 1936, or Nov. 30, 1936, if the applicant resides outside of the United States or Canada.

Allen, H. J., Allen Engineering Company, Marshall, Texas.
Allen, T. H. (Member), Board of Light and Water Commissioners, Memphis, Tenn.
Conrod, G. R., Northern Electric Company Ltd., Toronto, Ontario, Can.
Cox, W. R., General Electric Company, River Works, Lynn, Mass.
Cunningham, E. W., Equipment Engineering Company, Los Angeles, Calif.
Feldman, S. N., Pacific Electric Company, Oakland, Calif.
Gerard, H., Greeley and Hanson, Chicago, Ill.
Gregory, C. M., Canadian National Railways, Winnipeg, Manitoba, Canada.
Ivanoff, B. P. (Member), 37 Bright St., Toronto, 2, Ontario, Can.
Jerde, N. G., Kirk Power Plant, Lead, So. Dak.
Melton, E. M., National Carbon Company Inc., 30 East 42nd Street, New York, N. Y.
Merrow, L. E. (Member), Rockland Light and Power Company, Nyack, N. Y.
Montgomery, T. B., Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
Osborne, H. W., Bureau of Electric Service, Milwaukee, Wis.
Palmer, G. E. (Fellow), Palmer Electric and Manufacturing Company, Waltham, Mass.
Parker, F. F., Hawthorne, Nev.
Pringle, L. A., Bureau of Power and Light, Los Angeles, Calif.
Reimers, T. D. (Member), New York Edison Company, Inc., New York, N. Y.
Russell, C. C. (Member), Radio Station WTAM, Brecksville, Ohio.
Schappert, E. L., Luzerne County Gas and Electric Corporation, Kingston, Pa.
Tilton, O. A., General Electric Company, Schenectady, N. Y.
Upchurch, J. B., 545 Harvey-Snider Building, Wichita Falls, Texas.
Wearn, G. E., Jr., 315 Summit Ave., Wayne, Pa.
Yost, I. A., Westinghouse Electric and Manufacturing Company, Cleveland, Ohio.

24 Domestic

Foreign

Caffin, R. F., City Electric Light Company Ltd., Boundary Street, Brisbane, Queensland, Australia.
De Freitas, J. S., Sao Paulo Tramway, Light and Power Company Ltd., Caixa Postal a, Sao Paulo, Brazil.
Gray, J. D., N.W. Woods, Ltd., Colchester, England.
Handa, J. R., Northwestern Railway Company Lahore, India.

4 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as they now appear on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Bukley, E. J., Malaja-Dmitrovka D. 8 Kv. 38, Moscow, U.S.S.R.
Burns, Arthur E., 1958 E. 29th St., Brooklyn, N. Y.
Collins, Ogie B., Minimum, Mo.
Eiler, E. E., 101 Brookline Court, Upper Darby, Pa.
Jones, Harry Kenneth, 5511 Kenmore Ave., Chicago, Ill.
Koch, Joseph Stanley, 11 Howe Ave., New Rochelle, N. Y.
Luther, Herbert A., 50 Atwood Ave., Johnston, R. I.
Megeath, S. A., Jr., 14 North Ave., Elizabeth, N. J.
Millheisler, Charles A., 1417 Catalpa Ave., Chicago, Ill.
Miyota, Nath S., 916$^1/_2$ Howell St., Seattle, Wash.
Pollastro, John B., Helper, Utah.
Ridenhour, W. L., 216 Vance St., Chapel Hill, N. C.
Walstra, W. G., Y. M. C. A., Boise, Idaho.
Willson, William H., Jr., 1720—2nd Ave., Cedar Rapids, Iowa.
Wong, Harry Y. L., 771 Broadway, West New York, N. J.

15 Addresses Wanted

Officers and Committees for 1936-37

President

A. M. MacCUTCHEON	Cleveland, Ohio

(Term expires July 31, 1937)

Junior Past-Presidents

J. B. WHITEHEAD	Baltimore, Md.

(Term expires July 31, 1937)

E. B. MEYER	Newark, N. J.

(Term expires July 31, 1938)

Vice Presidents

Dist. No.		
(2)	W. H. HARRISON	Philadelphia, Pa.
(4)	MARK ELDREDGE	Memphis, Tenn.
(6)	R. H. FAIR	Omaha, Neb.
(8)	N. B. HINSON	Los Angeles, Calif.
(10)	C. V. CHRISTIE	Montreal, Que.

(Terms expire July 31, 1937)

(1)	A. C. STEVENS	Schenectady, N. Y.
(3)	O. B. BLACKWELL	New York, N. Y.
(5)	C. F. HARDING	Lafayette, Ind.
(7)	L. T. BLAISDELL	Dallas, Tex.
(9)	C. E. ROGERS	Seattle, Wash.

(Terms expire July 31, 1938)

Directors

P. B. JUHNKE	Chicago, Ill.
EVERETT S. LEE	Schenectady, N. Y.
L. W. W. MORROW	New York, N. Y.

(Terms expire July 31, 1937)

F. M. FARMER	New York, N. Y.
N. E. FUNK	Philadelphia, Pa.
H. B. GEAR	Chicago, Ill.

(Terms expire July 31, 1938)

F. ELLIS JOHNSON	Columbia, Mo.
C. R. JONES	New York, N. Y.
W. B. KOUWENHOVEN	Baltimore, Md.

(Terms expire July 31, 1939)

K. B. McEACHRON	Pittsfield, Mass.
C. A. POWEL	East Pittsburgh, Pa.
R. W. SORENSEN	Pasadena, Calif.

(Terms expire July 31, 1940)

National Treasurer

W. I. SLICHTER	New York, N. Y.

(Term expires July 31, 1937)

National Secretary

H. H. HENLINE	New York, N. Y.

(Term expires July 31, 1937)

General Counsel

Parker & Aaron
20 Exchange Place, New York, N. Y.

Local Honorary Secretaries

AUSTRALIA—V. J. F. Brain, Department of Public Works, Phillip St., Sydney, N. S. W.
BRAZIL—F. M. Servos, Rio de Janeiro Tramway Light & Power Co., Rio de Janeiro, Brazil, S. A.
ENGLAND—A. P. M. Fleming, Metropolitan Vickers Elec. Co., Trafford Park, Manchester.
FRANCE—A. S. Garfield, 173 Boulevard Haussmann. Paris, 8E.
INDIA—H. P. Thomas, Oriental Building, The Mall, Lahore, Punjab
ITALY—Renzo Norsa, Piazza Irnerio 8, Milano.
NEW ZEALAND—P. H. Powell, Canterbury College, Christchurch.
SWEDEN—A. F. Enstrom, Ingeniorsvetenskrapsakademien, Stockholm.
TRANSVAAL—W. Elsdon-Dew, P. O. Box 4563, Johannesburg, Transvaal, Africa.

GENERAL COMMITTEES

Executive

A. M. MacCutcheon, Chm., 1088 Ivanhoe Rd., Cleveland, Ohio.
O. B. Blackwell
W. H. Harrison
Everett S. Lee
E. B. Meyer
L. W. W. Morrow
W. I. Slichter

Board of Examiners

Harold C. Dean, Chm., 28-19 Bridge Plaza North, Long Island City, N. Y.
H. E. Farrer, Secy., AIEE., 33 W. 39th St., New York, N. Y.
T. F. Barton
F. E. D'Humy
F. M. Farmer
Harold Goodwin, Jr.
H. A. Kidder
S. D. Sprong
F. V. Magalhaes
R. H. Marriott
L. W. W. Morrow
A. L. Powell
H. E. Shreeve

Code of Principles of Professional Conduct

H. V. Carpenter, Chm., State College of Washington, Pullman, Wash.
L. W. Chubb
D. C. Jackson
F. B. Jewett
E. B. Meyer
H. T. Plumb
C. E. Stephens

Columbia University Scholarships

W. I. Slichter, Chm., Columbia University, New York, N. Y.
Francis Blossom
H. C. Carpenter

Constitution and By-Laws

R. N. Conwell, Chm., Public Service Electric & Gas Co., 80 Park Place, Newark, N. J.
C. O. Bickelhaupt
H. A. Kidder
W. I. Slichter
W. K. Vanderpoel

Co-ordination of Institute Activities

L. W. W. Morrow, Chm., Electrical World, 330 W. 42d St., New York, N. Y.
R. N. Conwell
H. H. Henline
Everett S. Lee
W. R. Smith
I. Melville Stein
W. H. Timbie

Economic Status of the Engineer

R. W. Sorensen, Chm., California Institute of Technology, Pasadena, Calif.
T. F. Barton
C. O. Bickelhaupt
A. H. Lovell
Charles F. Scott

Edison Medal

Appointed by the President for term of 5 years

Gano Dunn	H. S. Osborne	C. E. Stephens
		(Terms expire July 31, 1937)
V. Bush	H. P. Charlesworth, Chm.	K. S. Wyatt
		(Terms expire July 31, 1938)
H. B. Gear	L. C. Nichols	J. B. Whitehead
		(Terms expire July 31, 1939)
F. J. Meyer	R. A. Millikan	Marion Penn
		(Terms expire July 31, 1940)
G. L. Knight	H. W. Osgood	W. S. Rodman
		(Terms expire July 31, 1941)

Appointed by the Board of Directors from its own membership for term of 2 years

W. H. Harrison	W. B. Kouwenhoven	C. R. Jones
		(Terms expire July 31, 1937)
F. M. Farmer	C. E. Rogers	A. C. Stevens
		(Terms expire July 31, 1938)

Ex-officio

A. M. MacCutcheon, president
W. I. Slichter, national treasurer
H. H. Henline, national secretary
(Terms expire July 31, 1937)

Finance

Everett S. Lee, Chm., General Electric Co., Schenectady, N. Y.
N. E. Funk
C. R. Jones
L. W. W. Morrow

Headquarters

F. M. Farmer, Chm., Electrical Testing Laboratories, 80th St. & East End Ave., New York, N. Y.
H. H. Henline
Everett S. Lee

Institute Policy

J. B. Whitehead, Chm., Johns Hopkins University, Baltimore, Md.
A. W. Berresford
H. P. Charlesworth
B. Gherardi
D. C. Jackson
J. E. Kearns
L. W. W. Morrow

Iwadare Foundation

F. B. Jewett, Chm., 195 Broadway, New York, N. Y.
J. W. Barker
H. H. Barnes, Jr.

Lamme Medal

L. E. Imlay	F. B. Jewett	A. M. MacCutcheon
		(Terms expire July 31, 1937)
L. W. Chubb	N. E. Funk, Chm.	W. H. Harrison
		(Terms expire July 31, 1938)
V. Bush	C. R. Jones	D. C. Prince
		(Terms expire July 31, 1939)

Legislation Affecting the Engineering Profession

T. F. Barton, Chm., General Electric Co., 570 Lexington Ave., New York, N. Y.
J. P. Alexander
B. M. Brigman
D. T. Canfield
H. C. Dean
O. J. Ferguson
N. E. Funk
W. H. Harrison
D. C. Jackson
L. W. W. Morrow
L. S. Ready
C. E. Rogers
Herbert S. Sands
M. R. Scharff
J. B. Thomas

Membership

G. A. Kositzky, Chm., The Ohio Bell Telephone Co., 750 Huron Rd., Cleveland, Ohio
R. L. Webb, Asst. Chm., Brooklyn Edison Co., 380 Pearl St., Brooklyn, N. Y.
T. F. Ball
C. L. Dawes
P. G. Edwards
Joseph Hellenthal
M. W. Smith
Everett S. Lee
C. J. MacDonald
J. R. MacGregor
R. G. Meyerand

District Vice Chairmen

J. Leo Scanlon (1)
E. S. Fields (2)
J. E. McCormack (3)
James M. Todd (4)
C. A. Cora (5)
C. P. Kahler (6)
E. T. Gunther (7)
F. B. Doolittle (8)
John Bankus (9)
A. B. Cooper (10)

Ex-officio

Chairmen of membership committees of all Sections

New York Museum of Science and Industry, Advisory Committee to

J. P. Jackson, Chm., New York Edison Co., 4 Irving Place, New York, N. Y.
R. H. Hughes
R. H. Nexsen

Prizes, Award of Institute

W. R. Smith, Chm., Public Service Electric & Gas Co., 80 Park Place, Newark, N. J.
O. W. Eshbach
I. Melville Stein
W. B. Kouwenhoven

Publication

I. Melville Stein, Chm., Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia, Pa.
F. A. Lewis, Secy., AIEE, 33 W 39th St., New York, N. Y.
C. O. Bickelhaupt
J. W. Barker
O. W. Eshbach
H. H. Henline
L. W. W. Morrow
D. M. Simmons
W. R. Smith
W. H. Timbie

Safety Codes

H. S. Warren, Chm., 463 West St., New York, N. Y.
L. F. Adams
A. W. Berresford
G. S. Diehl
F. D. Knight
W. B. Kouwenhoven
M. G. Lloyd
H. H. Weber
Wills Maclachlan
F. V. Magalhaes
A. C. Marshall
H. N. Pye
Frank Thornton, Jr.
W. C. Wagner

Sections

W. H. Timbie, Chm., Massachusetts Institute of Technology, Cambridge, Mass.
W. M. Dann
Mark Eldredge
O. W. Holden
E. T. Mahood
H. H. Race
I. Melville Stein

Ex-officio

Chairmen of all Institute Sections

Standards

V. M. Montsinger, Chm., General Electric Co., Pittsfield, Mass.

H. E. Farrer, Secy., AIEE, 33 W. 39th St., New York, N. Y.

O. B. Blackwell
C. R. Harte
R. E. Hellmund
R. T. Henry
A. H. Kehoe
J. Franklin Meyer
E. L. Moreland
S. H. Mortensen
E. B. Paxton
H. W. Price

Ex-officio

Chairmen of working committees
Chairman of AIEE delegations on other standardizing bodies or sole representative thereon.
President of U. S. National Committe of International Electrotechnical Commission.

Student Branches

F. Ellis Johnson, Chm., University of Missouri, Columbia, Mo.

Edward Bennett
L. A. Doggett
E. E. Dreese
O. E. Edison
O. W. Eschbach
T. W. Fitzgerald
E. A. Loew
Charles F. Scott
R. W. Sorensen

Ex-officio

Student Branch counselors

Technical Program

W. R. Smith, Chm., Public Service Electric & Gas Co., 80 Park Place, Newark, N. J.

C. S. Rich, Secy., AIEE, 33 W. 39th St., New York, N. Y.

J. W. Barker
H. S. Bennion
R. N. Conwell
J. F. H. Douglas
E. J. O'Connell
M. W. Smith
I. Melville Stein
T. A. Worcester

Ex-officio

Chairmen of technical committees
Chairman of committee on co-ordination of Institute activities

Transfers

Harold Goodwin, Jr., Chm., 313 Maple Ave., Wyncote, Pa.

F. M. Craft
H. C. Don Carlos
C. F. Harding
J. E. Kearns
F. O. McMillan

TECHNICAL COMMITTEES

Automatic Stations

M. E. Reagan, Chm., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

F. F. Ambuhl
A. E. Anderson
R. B. Arthur
Alfred Chetham-Strode
H. W. Codding
F. S. Douglass
W. L. Eyres
Joseph Hellenthal
P. B. Juhnke
J. T. Logan
I. E. Moultrop
Charles A. Muller
C. F. Publow
O. J. Rotty
H. P. Sedwick
Garland Stamper
L. J. Turley
Chester Wallace

Communication

C. B. Jolliffe, Chm., Radio Corp. of America, 30 Rockefeller Plaza, New York, N. Y.

C. B. Aiken
A. L. Albert
W. C. Ballard, Jr.
H. H. Beverage
E. L. Bowles
L. W. Chubb
J. L. Clarke
A. A. Clokey
H. J. Dible
Melville Eastham
W. L. Everitt
R. H. Fair
E. E. George
G. H. Gray
W. F. Grimes
H. H. Haglund
J. W. Hannon
H. L. Huber
T. Johnson, Jr.
M. J. Kelly
H. E. Kent
J. R. MacGregor
E. J. O'Connell
H. S. Osborne
J. J. Pilliod
H. Pratt
M. A. Sawyer
E. R. Shute
Burke Smith
H. W. Sundius
A. H. Taylor
C. H. Taylor
F. E. Terman
J. R. Tolmie
H. M. Turner
M. P. Weinbach
W. C. White
R. S. Wishart
F. A. Wolff
F. C. Young

Education

O. W. Eshbach, Chm., American Tel. & Tel. Co., 195 Broadway, New York, N. Y.

J. W. Barker
Robin Beach
F. C. Bolton
H. V. Carpenter
J. C. Clark
A. S. Langsdorf
F. E. Johnson
A. D. Moore
T. H. Morgan
E. L. Moreland
J. A. Correll
E. E. Dreese
A. M. Dudley
H. S. Evans
O. J. Ferguson
W. E. Freeman
C. F. Harding
Albrecht Naeter
R. C. Putnam
W. S. Rodman
R. W. Sorensen
A. R. Stevenson, Jr.
F. E. Terman
R. I. Wilkinson

Electric Welding

H. M. Hobart, Chm., General Electric Co., Schenectady, N. Y.

C. A. Adams
J. H. Blankenbuehler
A. M. Candy
W. E. Crawford
Frederick Creedy
J. W. Dawson
Saul Dushman
D. D. Ewing
K. L. Hansen
C. J. Holslag
G. G. Landis
Hermann Lemp
J. C. Lincoln
A. C. Stevens
H. E. Stoddard
Malcolm Thomson
H. A. Winne

Electrical Machinery

J. L. Hamilton, Chm., 1806 Pine St., St. Louis, Mo.

P. H. Adams
P. L. Alger
E. S. Bundy
J. E. Clem
W. M. Dann
J. F. Fairman
M. S. Hancock
F. E. Harrell
C. A. Harrington
E. W. Henderson
F. B. Hynes
C. E. Johnson
F. E. Johnson
Charles Kingsley, Jr.
C. M. Laffoon
F. C. Lindvall
O. K. Marti
V. M. Montsinger
S. H. Mortensen
J. R. North
E. B. Paxton
F. D. Phillips
W. I. Slichter
J. D. Swering
C. G. Veinott
G. A. Waters

Electrochemistry and Electrometallurgy

F. O. Schnure, Chm., Bethlehem Steel Co., Bethlehem, Pa.

F. C. Andrae
E. L. Bailey
G. H. Clamer
C. Dantsizen
C. L. Dudley
F. W. Godsey, Jr.
W. C. Kalb
W. B. Kouwenhoven
C. C. Levy
Allan Monkhouse
J. D. Noyes
E. M. Richards
W. R. Schofield
M. F. Skinker
N. R. Stansel
C. P. Yoder

Electrophysics

R. C. Mason, Chm., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

S. S. Attwood
A. Boyajian
O. E. Buckley
J. O'R. Coleman
W. F. Davidson
E. E. Dreese
L. O. Grondahl
V. Karapetoff
H. P. Lawther, Jr.
F. C. Lindvall
M. G. Malti
K. B. McEachron
F. O. McMillan
H. H. Race
F. A. Rogers
C. S. Roys
Joseph Slepian
Ernst Weber
J. P. Youtz

Instruments and Measurements

H. C. Koenig, Chm., Electrical Testing Laboratories, 80th St. & East End Ave., New York, N. Y.

H. S. Baker
C. E. Bathe
T. M. Blakeslee
H. B. Brooks
A. L. Brownlee
J. S. Cruikshank
Marion Eppley
W. N. Goodwin, Jr.
C. H. G. Gray
T. S. Gray
S. S. Green
I. F. Kinnard
W. B. Kouwenhoven
Everett S. Lee
Paul MacGahan
H. W. Price
H. R. Richardson
A. C. Seletzky
W. J. Shackelton
G. M. L. Sommerman
H. L. Thomson
H. M. Turner
Joseph Weil
D. A. Young

Iron and Steel Production, Applications to

Wray Dudley, Chm., National Tube Co., Frick Bldg., Pittsburgh, Pa.

F. B. Crosby
A. C. Cummins
James Dixon
C. W. Fick
E. Gordon Fox
R. W. Graham
F. E. Harrell
D. M. Petty
F. O. Schnure
E. W. Seeger
A. C. Stevens
L. A. Umansky
A. J. Whitcomb
H. A. Winne
R. H. Wright

Light, Production and Application of

A. L. Powell, Chm., General Electric Co., 570 Lexington Ave., New York, N. Y.

D. W. Atwater
J. W. Barker
Robin Beach
W. T. Blackwell
L. T. Blaisdell
H. B. Dates
E. E. Dorting
C. L. Dows
C. W. Franklin
L. A. Hawkins
H. H. Higbie
W. C. Kalb
R. D. Mailey
P. S. Millar
E. M. Strong
A. N. Topping

Marine Work, Applications to

A. Kennedy, Jr., Chm., Marine Engg. Dept., General Electric Co., Schenectady, N. Y.

E. C. Alger
R. A. Beekman
H. C. Coleman
E. M. Glasgow
H. F. Harvey, Jr.
C. J. Henschel
Wm. Hetherington, Jr.
J. B. Lunsford
I. H. Osborne
G. A. Pierce
C. A. Powel
W. H. Reed
H. M. Southgate
A. E. Waller
O. A. Wilde
R. L. Witham
W. N. Zippler

Mining Work, Applications to

J. H. Edwards, Chm., 2962 Winters Rd., Huntington, W. Va.

J. E. Borland
C. A. Faust
M. W. Gilliam
A. A. Hall
L. C. Ilsley
L. H. James
R. L. Kingsland
L. W. W. Morrow
H. P. Musser
D. E. Renshaw
G. W. Swenson
E. B. Wagner
J. F. Wiggert
C. D. Woodward

Power Applications, General

H. W. Rogers, Chm., Industrial Dept., General Electric Co., Schenectady, N. Y.

E. A. Armstrong
R. F. Chamberlain
C. W. Drake
J. F. Gaskill
P. B. Juhnke
A. E. Knowlton
F. T. Leilich
F. J. Meyer
J. B. Thomas
L. M. Shadgett
R. L. Walsh
C. J. White
F. Zogbaum

Power Generation

G. M. Armbrust, Chm., Commonwealth Edison Co., 72 West Adams St., Chicago, Ill.

C. C. Adams
H. C. Albrecht
F. A. Annett
W. L. Cisler
H. M. Cushing
S. M. Dean
J. H. Foote
R. L. Frisby
N. B. Hinson
F. H. Hollister
S. J. Lisberger
G. A. Mills
E. F. Pearson
G. G. Post
C. A. Powel
H. R. Sills
A. E. Silver
W. F. Sims
Philip Sporn
E. C. M. Stahl
Robert Treat
H. L. Wallau
H. E. Wulfing

Power Transmission and Distribution

C. T. Sinclair, Chm., Byllesby Engg. & Mgt. Corp., 435 Sixth Ave., Pittsburgh, Pa.

Raymond Bailey
A. E. Bauhan
D. K. Blake
M. O. Bolser
A. B. Campbell
J. S. Carroll
C. V. Christie
Harold Cole
R. N. Conwell
L. E. Cook
M. T. Crawford
A. E. Davison
F. W. Deck
Mark Eldredge
R. D. Evans
D. D. Ewing
F. M. Farmer
C. L. Fortescue
C. W. Franklin
E. D. Freeman
Herman Halperin
Edwin Hansson
K. A. Hawley
L. F. Hickernell
C. R. Higson
D. C. Jackson, Jr.
J. P. Jollyman
W. W. Lewis
E. A. Loew
E. W. Oesterreich
J. S. Parsons
H. J. Scholz
G. B. Shanklin
A. E. Silver
D. M. Simmons
L. G. Smith
Philip Sporn
Stanley Stokes
J. J. Torok
W. K. Vanderpoel
H. S. Warren
A. M. Wilson
E. M. Wood
L. F. Woodruff
T. A. Worcester
H. E. Wulfing

Protective Devices

J. P. McKearin, Chm., 73 State St., Springfield, Mass.

J. C. Balsbaugh
J. A. Brooks
J. O'R. Coleman
H. W. Collins
M. T. Crawford
L. N. Crichton
F. R. Ford
E. E. George
G. W. Gerell
S. L. Goldsborough
S. M. Hamill, Jr.
C. F. Harding
R. T. Henry
L. F. Hunt
B. M. Jones
A. V. Joslin
T. G. LeClair
W. A. Lewis
H. J. Lingal
F. R. Longley
M. H. Lovelady
J. B. MacNeill
K. B. McEachron
C. A. Muller
J. R. North
H. V. Nye
H. W. Osgood
D. C. Prince
H. K. Sels
H. P. Sleeper
L. G. Smith
R. M. Smith
H. R. Summerhayes
A. H. Sweetnam
J. J. Torok
O. C. Traver
H. M. Trueblood
E. C. Williams
E. M. Wood

Research

W. B. Kouwenhoven, Chm., Johns Hopkins University, Baltimore, Md.

R. W. Atkinson
O. E. Buckley
L. W. Chubb
E. H. Colpitts
E. C. Crittenden
O. G. C. Dahl
W. F. Davidson
F. M. Farmer
H. Halperin
F. Hamburger, Jr.
L. A. Hawkins
H. M. Hobart
V. Karapetoff
A. E. Kennelly
K. W. Miller
T. D. Owens
K. K. Paluev
H. H. Race
D. W. Roper
John M. Smith
G. M. L. Sommerman
T. Spooner
Ernest Weber
A. J. Williams
C. H. Willis
R. J. Wiseman
K. S. Wyatt

Transportation

G. I. Wright, Chm., Reading Co., Reading Terminal, Philadelphia, Pa.

R. Beeuwkes
C. M. Davis
E. G. Davis
J. V. B. Duer
D. D. Ewing
E. B. Fitzgerald
N. E. Funk
J. E. Gardner
W. A. Giger
Selby Haar
W. S. H. Hamilton
C. R. Jones
L. C. Josephs
A. J. Klatte
H. N. Latey
J. J. Linebaugh
P. A. McGee
E. L. Moreland
John Murphy
A. J. Nichol
N. W. Storer
L. J. Turley
W. M. Vandersluis
Sidney Withington
F. E. Wynne

INSTITUTE REPRESENTATIVES

Alfred Noble Prize Committee, ASCE

W. R. Smith

Am. Assoc. for the Advt. of Science, Council

V. Karapetoff
J. B. Whitehead

American Committee on Marking of Obstructions to Air Navigation

R. N. Conwell
H. L. Huber

American Engg. Council Assembly

C. O. Bickelhaupt
F. J. Chesterman
A. M. MacCutcheon
Wm. McClellan
C. E. Stephens
H. H. Henline, *Alternate*

American Marine Standards Committee

R. A. Beekman

American Stds. Assoc., Standards Council

A. M. MacCutcheon
E. L. Moreland

Alternates

H. S. Osborne
E. B. Paxton

American Stds. Assoc. Bd. of Directors

H. P. Charlesworth

American Year Book, Advisory Board

H. H. Henline

Bureau of Welding Research

H. M. Hobart

Charles A. Coffin Fellowship and Research Fund Committee

A. M. MacCutcheon

Com. of Apparatus Makers and Users, NRC

L. F. Adams

Com. on Heat Transmission, NRC

T. S. Taylor

Local Sections of the Institute

Name	District	Chairman	Secretary	Secretary's Address
Akron	2	H. H. Schroeder	L. M. Grow	Central Ohio Light & Power Co., Wooster, Ohio
Alabama	4	C. S. Thorn		
Atlanta	4			
Baltimore	2	R. L. Thomas	J. H. Lampe	Johns Hopkins University, Baltimore, Md.
Boston	1	C. L. Dawes	J. M. Murray	66 Sidney St., Cambridge, Mass.
Central Indiana	5	F. L. Stanley	L. G. Anderson	1150 W. Washington St., Indianapolis, Ind.
Chicago	5	Burke Smith	J. A. Fitts	4613 S. Western Ave., Chicago, Ill.
Cincinnati	2	A. C. Burroway	O. C. Schlemmer	225 E. Fourth St., Cincinnati, Ohio
Cleveland	2	W. E. Wickenden	W. C. Kalb	National Carbon Co. Inc., Cleveland, Ohio
Columbus	2	E. E. Kimberly	V. Frederiksen	347—15th Ave., Columbus, Ohio
Connecticut	1	E. D. Lynch	H. W. Sundius	Southern New England Telephone Co., New Haven, Conn.
Dallas	7	L. B. Cook	O. S. Hockaday	P. O. Box 970, Fort Worth, Texas
Denver	6	H. F. McPhail	R. H. Owen	National Broadcasting Co., 1625 California St., Denver, Colo.
Detroit-Ann Arbor	5	S. S. Attwood	D. H. Baker	Michigan Bell Telephone Co., 1365 Cass Ave., Detroit, Mich.
East Tennessee	4	J. H. Persons	M. Candler	Southern Bell Tel. & Tel. Co., Atlanta, Ga.
Erie	2	J. W. Teker	W. D. Bearce	4121 Sassafras St., Erie, Pa.
Florida	4	W. A. Smith	Joseph Weil	University of Florida, Gainesville, Fla.
Fort Wayne	5	D. H. Hanson	C. S. Allen	General Electric Co., 1635 Broadway, Fort Wayne, Ind.
Houston	7	M. C. Hughes	V. O. Clements	1209 Sterling Bldg., Houston, Texas
Iowa	5	F. H. McClain	R. R. Whipple	University of Iowa, Iowa City, Iowa
Ithaca	1	R. F. Chamberlain	True McLean	Cornell University, Ithaca, N. Y.
Kansas City	7	A. L. Maillard	A. F. Hartung	Burns & McDonnell Engineering Co., 107 W. Linwood, Kansas City, Mo.
Lehigh Valley	2	G. E. Northup	W. A. Everson	Hall & Maple Sts., Allentown, Pa.
Los Angeles	8	J. C. Gaylord	David Hall	Westinghouse Elec. & Mfg. Co., 420 S. San Pedro St., Los Angeles, Calif.
Louisville	4	Stanley Warth	F. W. Russell	119 N. Third St., Louisville, Ky.
Lynn	1	T. A. Abbott	C. F. Savage	General Electric Co., West Lynn, Mass.
Madison	5	R. R. Benedict	W. A. Kuehlthau	441 W. Johnson St., Madison, Wis.
Memphis	4	E. A. Corum	P. G. Cartwright	P. O. Box 388, Memphis, Tenn.
Mexico	3	F. Aubert	E. R. Ericsson	2-A, Victoria 53–61, Mexico City, Mexico
Milwaukee	5	J. A. Potts	M. X. Moser	Wisconsin Telephone Co., 722 No. Broadway, Milwaukee, Wis.
Minnesota	5	J. H. Kuhlmann	C. H. Nelson	Main Engineering Bldg., University of Minnesota, Minneapolis, Minn.
Montana	9	W. A. Boyer	J. A. Thaler	Montana State College, Bozeman, Mont.
Nebraska	6	H. M. Craig	J. C. Schultz	Omaha & Council Bluffs Street R. R. Co., Omaha, Nebr.
New Orleans	4	C. W. Ricker	F. E. Johnson	317 Baronne St., New Orleans, La.
New York	3	A. G. Oehler	A. L. Powell	General Electric Co., 570 Lexington Ave., New York, N. Y.
Niagara Frontier	1	J. L. Scanlon	N. E. Brown	Buffalo General Electric Co., 429 Electric Bldg., Buffalo, N. Y.
North Carolina	4	C. E. Waddell	J. F. Coleman	Champion Fibre Co., Canton, No. Carolina
Oklahoma City	7	E. D. Freeman	C. E. Bathe	Oklahoma Gas & Electric Co., Oklahoma City, Okla.
Philadelphia	2	O. C. Traver	H. S. Phelps	Philadelphia Electric Co., 2301 Market St., Philadelphia, Pa.
Pittsburgh	2	J. R. MacGregor	P. Frederick	General Electric Co., 463—7th Ave., Pittsburgh, Pa.
Pittsfield	1	K. B. McEachron	J. R. Meador	General Electric Co., 100 Woodlawn Ave., Pittsfield, Mass.
Portland	9	S. E. Caldwell	C. C. Boozier	Westinghouse Elec. & Mfg. Co., 309 S. W. Sixth Ave., Portland, Ore.
Providence	1	H. C. Rankin	R. J. Underwood	New England Power Service Co., Providence, R. I.
Rochester	1	E. H. Branson	B. M. Werly	Eastman Kodak Co., Rochester, N. Y.
St. Louis	7	H. R. Fritz	C. A. Loveless	C. B. Fall Co., 1205 Olive St., St. Louis, Mo.
San Antonio	7	E. G. Conroy	O. W. Sommers	San Antonio Public Service Co., San Antonio, Texas
San Francisco	8	H. S. Lane	F. S. Benson	Pacific Gas & Electric Co., 245 Market St., San Francisco, Calif.
Saskatchewan	10	W. L. Campkin	James Smith	Canada Wire & Cable Co. Ltd., Regina, Sask., Can.
Schenectady	1	C. M. Foust	E. M. Hunter	General Electric Co., Schenectady, N. Y.
Seattle	9	R. Beeuwkes	R. F. Stevens	Seattle Municipal Light & Power System, Seattle, Wash.
Sharon	2	J. H. Chiles	H. S. Smith	Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Spokane	9	R. D. Sloan	H. A. Stingle	1412 E. 15th Ave., Spokane, Wash.
Springfield	1	C. G. Veinott	W. O. Henschke	274 Locust St., Springfield, Mass.
Syracuse	1	G. E. Tennant	R. A. P. Jones	General Electric Co., 113 S. Salina St., Syracuse, N. Y.
Toledo	2	W. F. Brown	W. V. Gorton	901 Second National Bank Bldg., Toledo, Ohio
Toronto	10	V. G. Smith	D. G. Geiger	Bell Telephone Co. of Canada, 76 Adelaide St. W., Toronto, Ont., Can.
Urbana	5	H. J. Reich	W. J. Warren	University of Illinois, Urbana, Ill.
Utah	9	W. L. Winter	A. C. Kelm	Utah Power & Light Co., Salt Lake City, Utah
Vancouver	10	D. M. Johnstone	J. H. Steede	2557 Bellevue Ave., Hollyburn P. O., W. Vancouver, B. C., Can.
Virginia	4	J. E. Jackson	W. F. Nimmo	Virginia Electric & Power Co., P. O. Box 1194, Richmond, Va.
Washington	2	H. W. Osgood	T. R. Tate	Federal Power Commission, Washington, D. C.
Worcester	1	H. E. Carson	T. R. Holton	American Steel & Wire Co., Worcester, Mass.

Total 62

Electrical Standards Committee, ASA

A. M. MacCutcheon E. L. Moreland H. S. Osborne

Alternates

H. E. Farrer R. E. Hellmund E. B. Paxton

Engineering Foundation Board

F. M. Farmer W. I. Slichter

Engg. Societies Monographs Committee

F. Malcolm Farmer W. I. Slichter

Engineers' Council for Professional Development

C. O. Bickelhaupt L. W. W. Morrow C. F. Scott

Hoover Medal Board of Award

H. H. Barnes, Jr. Gano Dunn F. B. Jewett

John Fritz Medal Board of Award

A. W. Berresford E. B. Meyer
H. P. Charlesworth J. B. Whitehead

Library Board, United Engg. Trustees, Inc.

W. S. Barstow H. H. Henline
W. A. Del Mar W. I. Slichter

National Bureau of Engg. Registration, Advisory Board

W. I. Slichter

Nat. Fire Prot. Assoc. Electrical Committee

H. S. Warren F. V. Magalhaes, *Alternate*

National Fire Waste Council

F. V. Magalhaes H. S. Warren

Nat. Research Council, Division of Engg. and Industrial Research

V. Bush Everett S. Lee J. B. Whitehead

Ex-officio H. H. Henline

Nat. Safety Council, ASSE—Engg. Section, Com. on Low Voltage Hazards

H. S. Warren

Radio Advisory Com., Bur. of Standards

A. E. Kennelly

Research Procedure Com., Engg. Foundation

L. W. Chubb

Thomas Alva Edison Foundation

H. H. Barnes, Jr. Charles F. Scott
L. W. W. Morrow Clayton H. Sharp

United Engineering Trustees, Inc.

H. P. Charlesworth G. L. Knight H. R. Woodrow

U. S. National Committee of the International Commission on Illumination

A. E. Kennelly C. F. Scott C. H. Sharp

U. S. National Committee of the International Electrotechnical Commission

A. M. MacCutcheon E. L. Moreland H. S. Osborne

Alternates

H. E. Farrer R. E. Hellmund E. B. Paxton

Commission of Washington Award

L. A. Ferguson Wm. B. Jackson

Student Branches of the Institute

Name and Location	District	Counselor
Akron, Univ. of., Akron, Ohio	2	J. T. Walther
Alabama Poly. Inst., Auburn, Ala	4	W. W. Hill
Alabama, Univ. of, University, Ala	4	Fred R. Maxwell, Jr.
Arizona, Univ. of, Tucson, Ariz	8	J. C. Clark
Arkansas, Univ. of, Fayetteville, Ark	7	W. B. Stelzner
Armour Inst. of Tech., Chicago, Ill	5	E. H. Freeman
British Columbia, Univ. of, Vancouver, B. C.	10	E. G. Cullwick
Brooklyn, Poly. Inst. of Brooklyn, N. Y	3	C. C. Whipple
Brown Univ., Providence, R. I	1	F. N. Tompkins
Bucknell Univ., Lewisburg, Pa	2	G. A. Irland
Calif. Inst. of Tech., Pasadena, Calif	8	F. C. Lindvall
Calif., Univ. of, Berkeley, Calif	8	Abe Tilles
Carnegie Inst. of Tech., Pittsburgh, Pa	2	M. S. Schonvizner
Case Sch. of Ap. Science, Cleveland, Ohio	2	A. C. Seletzky
Catholic Univ. of America, Washington, D. C.	2	T. J. MacKavanagh
Cincinnati, Univ. of, Cincinnati, Ohio	2	L. R. Culver
Clarkson College of Tech., Potsdam, N. Y	1	A. R. Powers
Clemson Agri. Col., Clemson, So. Car	4	S. R. Rhodes
Colorado State Agri. Col., Fort Collins, Colo	6	H. G. Jordan
Colorado, Univ. of, Boulder, Colo	6	H. B. Palmer
Cooper Union, New York, N. Y	3	F. A. Tallman
Cornell Univ., Ithaca, N. Y	1	E. M. Strong
Denver, Univ. of, Denver, Colo	6	R. E. Nyswander
Detroit, Univ. of, Detroit, Mich	5	H. O. Warner
Drexel Inst., Philadelphia, Pa	2	E. O. Lange
Duke Univ., Durham, N. C	4	W. J. Seeley
Florida, Univ. of, Gainesville, Fla	4	Joseph Weil
George Washington Univ., Washington, D. C.	2	A. G. Ennis
Georgia Sch. of Tech., Atlanta, Ga	4	T. W. Fitzgerald
Harvard Univ., Cambridge, Mass	1	J. D. Cobine
Idaho, Univ. of, Moscow, Idaho	9	R. H. Hull
Illinois, Univ. of, Urbana, Ill	5	E. A. Reid
Iowa State Col., Ames, Iowa	5	B. S. Willis
Iowa, Univ. of, Iowa City, Iowa	5	G. F. Corcoran
Johns Hopkins Univ., Baltimore, Md	2	J. H. Lampe
Kansas State Col., Manhattan, Kan	7	L. M. Jorgenson
Kansas, Univ. of, Lawrence, Kan	7	E. W. Hamlin
Kentucky, Univ. of, Lexington, Ky	4	W. E. Freeman
Lafayette Col., Easton, Pa	2	F. W. Smith
Lehigh Univ., Bethlehem, Pa	2	J. L. Beaver
Lewis Inst., Chicago, Ill	5	F. A. Rogers
Louisiana State Univ., Baton Rouge, La	4	M. B. Voorhies
Louisville, Univ. of, Louisville, Ky	4	J. M. Houchens
Maine, Univ. of, Orono, Me	1	W. H. Bliss
Marquette Univ., Milwaukee, Wis	5	E. W. Kane
Maryland, Univ. of, College Park, Md	2	L. J. Hodgins
Mass. Inst. of Tech., Cambridge, Mass	1	W. H. Timbie
Michigan Col. of Min. & Tech., Houghton, Mich.	5	G. W. Swenson
Michigan State Col., E. Lansing, Mich	5	B. K. Osborn
Michigan, Univ. of, Ann Arbor, Mich	5	S. S. Attwood
Milwaukee Sch. of Engg., Milwaukee, Wis	5	A. L. Oklund
Minnesota, Univ. of, Minneapolis, Minn	5	J. H. Kuhlmann
Mississippi State Col., State College, Miss	4	L. H. Fox
Missouri Sch. of Mines and Met., Rolla, Mo	7	I. H. Lovett
Missouri, Univ. of, Columbia, Mo	7	M. P. Weinbach
Montana State College, Bozeman, Mont	9	J. A. Thaler
Nebraska, Univ. of, Lincoln, Nebr	6	L. A. Bingham
Nevada, Univ. of, Reno, Nev	8	S. G. Palmer
Newark Col. of Engg., Newark, N. J	3	J. C. Peet
New Hampshire, Univ. of, Durham, N. H	1	L. W. Hitchcock
New Mexico, Univ. of, Albuquerque, New Mexico	7	Chester Russell, Jr.
New York, Col. of the City of, New York, N. Y	3	Harry Baum
New York Univ., New York, N. Y	3	H. N. Walker
North Carolina State Col., Raleigh, N. C	4	R. S. Fouraker
North Carolina, Univ. of, Chapel Hill, N. C	4	E. W. Winkler
North Dakota State College, Fargo, No. Dak	6	H. S. Rush
North Dakota, Univ. of, Grand Forks, No. Dak	6	H. F. Rice
Northeastern Univ., Boston, Mass	1	W. L. Smith
Notre Dame, Univ. of, Notre Dame, Ind	5	J. A. Caparo
Ohio Northern Univ., Ada, Ohio	2	B. F. Wyandt
Ohio State Univ., Columbus, Ohio	2	F. C. Caldwell
Ohio Univ., Athens, Ohio	2	A. A. Atkinson
Oklahoma A. & M. Col., Stillwater, Okla	7	Albrecht Naeter
Oklahoma, Univ. of, Norman, Okla	7	C. T. Almquist
Oregon State Col., Corvallis, Ore	9	A. L. Albert
Pennsylvania State Col., State College, Pa	2	L. A. Doggett
Pennsylvania, Univ. of, Philadelphia, Pa	2	C. D. Fawcett
Pittsburgh, Univ. of, Pittsburgh, Pa	2	H. E. Dyche
Porto Rico, Univ. of, Mayaguez, P. R	3	
Pratt Institute, Brooklyn, N. Y	3	
Princeton Univ., Princeton, N. J	2	Malcolm MacLaren
Purdue Univ., Lafayette, Ind	5	J. H. Bowman
Rensselaer Poly. Inst., Troy, N. Y	1	F. M. Sebast
Rhode Island State Col., Kingston, R. I	1	W. B. Hall
Rice Institute, Houston, Texas	7	J. S. Waters
Rose Poly. Inst., Terre Haute, Ind	5	C. C. Knipmeyer
Rutgers Univ., New Brunswick, N. J	3	F. H. Pumphrey
Santa Clara, Univ. of, Santa Clara, Calif	8	E. F. Peterson
South Carolina, Univ. of, Columbia, S. C	4	
South Dakota State Col., Brookings, So. Dak	6	W. H. Gamble
So. Dak. State Sch. of Mines, Rapid City, S. D	6	J. O. Kammerman
Southern California, Univ. of, Los Angeles, Calif	8	W. G. Angermann
Southern Methodist Univ., Dallas, Texas	7	H. F. Huffman
Stanford Univ., Stanford University, Calif	8	H. H. Skilling
Stevens Inst. of Tech., Hoboken, N. J	3	
Swarthmore Col., Swarthmore, Pa	2	
Syracuse Univ., Syracuse, N. Y	1	C. W. Henderson
Tennessee, Univ. of, Knoxville, Tenn	4	J. G. Tarboux
Texas A. & M. Col., College Station, Texas	7	H. C. Dillingham
Texas Technological Col., Lubbock, Texas	7	C. V. Bullen
Texas, Univ. of, Austin, Texas	7	J. A. Correll
Tufts College, Tufts College, Mass	1	E. A. Walker
Union College, Schenectady, N. Y	1	E. J. Berg
Utah, Univ. of, Salt Lake City, Utah	9	A. L. Taylor
Vermont, Univ. of, Burlington, Vt	1	E. R. McKee
Villanova College, Villanova, Pa	2	H. S. Bueche
Virginia Military Inst., Lexington, Va	4	S. W. Anderson
Virginia Poly. Inst., Blacksburg, Va	4	Claudius Lee
Virginia, Univ. of, University, Va	4	J. S. Miller
Washington, State Col. of, Pullman, Wash	9	O. B. Osburn
Washington, Univ. of, Seattle, Wash	9	R. E. Lindblom
Washington Univ., St. Louis, Mo	7	H. G. Hake
West Virginia Univ., Morgantown, W. Va	2	A. H. Forman
Wisconsin, Univ. of, Madison, Wis	5	G. F. Tracy
Worcester Poly. Inst., Worcester, Mass	1	C. D. Knight
Wyoming, Univ. of, Laramie, Wyo	6	G. H. Sechrist
Yale Univ., New Haven, Conn	1	A. G. Conrad
Total 117		

Geographical District Executive Committees

District	Chairman (Vice-President, AIEE)	Secretary (District Secretary)
No. 1—North Eastern	A. C. Stevens, General Electric Co., Schenectady, N. Y.	R. G. Lorraine, General Electric Co., Schenectady, N. Y.
No. 2—Middle Eastern	W. H. Harrison, Bell Telephone Co. of Penna., 1835 Arch St., Philadelphia, Pa.	H. A. Dambly, Philadelphia Elec. Co., 900 Sansom St., Philadelphia, Pa.
No. 3—New York City	O. B. Blackwell, 463 West St., New York, N. Y.	A. L. Powell, General Electric Co., 570 Lexington Ave., New York, N. Y.
No. 4—Southern	Mark Eldredge, Memphis Power & Light Co., Memphis, Tenn.	R. F. Crenshaw, P. O. Box 439, Memphis, Tenn.
No. 5—Great Lakes	C. Francis Harding, Purdue University, Lafayette, Ind.	A. G. Dewars, Northern States Power Co., 15 S. 5th St., Minneapolis, Minn.
No. 6—North Central	R. H. Fair, Northwestern Bell Telephone Co., Omaha, Neb.	T. H. Granfield, Northwestern Bell Telephone Co., Room 1324 Telephone Bldg., Omaha, Neb.
No. 7—South West	L. T. Blaisdell, General Electric Co., 1801 N. Lamar St., Dallas, Tex.	L. C. Starbird, Room 820, Telephone Bldg., Dallas, Tex.
No. 8—Pacific	N. B. Hinson, Southern Calif. Edison Co., Edison Bldg., Los Angeles, Calif.	Fred Garrison, General Electric Co., 5201 Santa Fe Ave., Los Angeles, Calif.
No. 9—North West	C. E. Rogers, Pacific Tel. & Tel. Co., 1203 Telephone Bldg., Seattle, Wash.	Eugene L. White, Puget Sound Power & Light Co., Seattle, Wash.
No. 10—Canada	C. V. Christie, McGill University, Montreal, Quebec	J. M. Thomson, Ferranti Electric Ltd., Mount Dennis, Toronto 9, Ontario

Note: Each District executive committee includes the chairmen and secretaries of all Sections within the District and the chairman of the District committee on student activities.

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

RADIO AMATEUR'S HANDBOOK, the Standard Manual of Amateur Radio Communication by the Headquarters Staff of the American Radio Relay League. 1936 ed. West Hartford, Conn., American Radio Relay League. 472 p., illus., 10x7 in., paper, $1.00. The standard work on amateur radio communication, and useful as a reference book for the radio technician. All phases of construction and operation are discussed.

ENGLISH in BUSINESS and ENGINEERING By B. W. Stevenson, J. R. Spicer, E. G. Ames and C. F. Kettering. N. Y., Prentice-Hall, 1936. 365 p., illus., 9x6 in., cloth, $2.25. A useful reference book for the professional engineer and business man. Contains information on writing letters and articles, public speaking, and grammar.

ELECTRIC WIRING, a textbook of applied electricity for vocational and trade schools. By A. A. Schuhler. N. Y. and Lond., McGraw-Hill Book Co., 1936. 387 p., illus., 8x5 in., cloth, $2.50. Covers the fundamentals of electric wiring in a series of unit courses, and is intended for students in vocational schools.

EINFÜHRUNG in die SYMBOLISCHE METHODE der WECHSELSTROMTECHNIK (Die komplexe Vektorrechnung). By O. Müller. Leipzig, Max Jänecke Verlagsbuchhandlung, 1935. 93 p., illus., 8x6 in., paper, 4.80 rm. A text which requires only a knowledge of elementary mathematics, and intended as an introduction to more comprehensive treatises on alternating currents.

ANNUAL TABLES of CONSTANTS and NUMERICAL DATA: Chemical, Physical, Biological and Technological. v. 10, 1930, pt: 2. N. Y., McGraw-Hill Book Co., 1935. 609 p., illus., 11x9 in., cloth, $20 for both parts. Desirable for any research library or scientific laboratory. It provides new numerical data in every field of science, and contains data on building materials, fuels and refractories, and metals and alloys.

JOB HUNTING and GETTING. By C. Belden. Boston, L. C. Page & Co., 1935. 297 p., 9x6 in., cloth, $2.50. A textbook on seeking employment. Suggests concrete ways of conducting a systematic campaign for a position.

HIGH SPEED DIESEL ENGINES. By J. Vanderdoes, L. H. Morrison, and C. T. Baker. Scranton, Pa., International Textbook Co., 1936. Illus., 8x5 in., lea., $1.80. Discusses the principles of these engines and describes the construction and operation of various types.

MODERN GLASS PRACTICE. By S. R. Scholes. Chicago, Industrial Publications, 1935. 344 p., illus., 9x6 in., cloth, $6.00. Provides a concise account of methods of glass making. Intended for students of glass technology, but of use to others who wish a general account of current practice.

THERMODYNAMICS for ENGINEERS. By the late J. A. Ewing. 2 ed. Cambridge, University Press; New York, Macmillan Co., 1936. 389 p., illus., 9x6 in., cloth, $6.00. A revision of Sir Alfred Ewing's well-known textbook.

SCIENCE and ART of ILLUMINATION. By C. E. Weitz. Scranton, Pa., International Textbook Co., 1935. Illus., 8x5 in., lea., $1.30. An elementary textbook, designed for home study.

PRACTICAL ELECTRICAL WIRING. By I. C. S. Staff. Scranton, Pa., International Textbook Co., 1934. Illus., 8x5 in., lea., $2.00. A textbook for home students. The approved methods of wiring buildings are described.

HYDROELECTRIC POWER STATIONS. By E. A. Crellin. Scranton, Pa., International Textbook Co., 1935. Illus., 8x5 in., lea., $1.60. An elementary text on design and construction which treats the subject descriptively.

Das ELEKTROAKUSTISCHE KLAVIER. By O. Vierling. Berlin, VDI-Verlag, 1936. 50 p., illus., 8x6 in., paper, 3.50 rm. Describes studies of sound waves and their transformation into electric waves; also describes an electroacoustic piano.

Théorie et Technologie des ENGRENAGES. v. 3, Les Transmissions par Engrenages. By J. Perignon. Paris, Dunod, 1936. 78 p., illus., 10x6 in., 28 frs. cloth; 19 frs. paper. This volume on gearing treats briefly and practically of transmission gearing. Statics and dynamics are discussed. Contains a chapter on gearing for electric locomotives and another on reducing gearing for ships.

Textbook of the MATERIALS of ENGINEERING. By H. F. Moore; with a chapter on Concrete by H. F. Gonnerman; and a chapter on the Crystalline Structure of Metals, by J. O. Draffin. 5 ed. N. Y. and Lond., McGraw-Hill Book Co., 1936. 419 p., illus., 9x6 in., cloth, $4.00. Discusses physical properties of common materials used in structures and machines, and describes their manufacture and fabrication.

ROYAL TECHNICAL COLLEGE JOURNAL, v. 3, pt. 4, January 1936. p. 531–698. Glasgow, Scotland, Royal Tech. College. illus., 10x7 in., 10s 6d. paper. A record of research work carried out recently in the college. Contains papers on measurement of sound transmission and conductivity of a broken glass surface.

CHEMICAL DISCOVERY and INVENTION in the TWENTIETH CENTURY. By Sir W. A. Tilden, rev. by S. Glasstone. N. Y., E. P. Dutton and Co., 1936. 492 p., illus., 9x6 in., cloth, $4.00. Provides a readable account of modern developments in chemistry that will interest general readers and science students. Modern discoveries and theories are discussed, and a section on industrial applications of chemistry is included.

PRINCIPLES of RADIO ENGINEERING. By R. S. Glasgow. N. Y. and Lond., McGraw-Hill Book Co., 1936. 520 p., illus., 9x6 in., cloth, $4.00. Presents the fundamentals of radio communication and their applications. Discusses in detail the theory and application of the vacuum tube and its associated circuits to communication systems. Mathematical developments are used freely, but do not extend beyond the preparation usually included in undergraduate engineering courses.

RESONANCE and ALIGNMENT. By John F. Rider, N. Y., 1936. 91 p., illus., 8x6 in., paper, $0.60. Intended for the radio service man. Reviews tuned circuits and explains the method for aligning receivers of various types.

WERKSTOFFKUNDE der HOCHVAKUUMTECHNIK. By W. Espe and M. Knoll. Berlin, Julius Springer, 1936. 383 p., illus., 10x7 in., cloth, 48 rm. A presentation of the properties, manipulation, and uses of the materials used in the construction of radio tubes, incandescent lamps, and other high vacuum apparatus.

WIRELESS SERVICING MANUAL. By W. T. Cocking. *Wireless World*, Iliffe and Sons, Lond., 1936. 213 p., illus., 8x5 in., cloth, 5s. A manual for the radio repairman, covering the principles and practice of repairing and adjustment.

Engineering Societies Library

29 West 39th Street, New York, N. Y.

MAINTAINED as a public reference library of engineering and the allied sciences, this library is a cooperative activity of the national societies of civil, electrical, mechanical, and mining engineers.

Resources of the library are available also to those unable to visit it in person. Lists of references, copies or translation of articles, and similar assistance may be obtained upon written application, subject only to charges sufficient to cover the cost of the work required.

A collection of modern technical books is available to any member residing in North America at a rental rate of five cents per day per volume, plus transportation charges.

Many other services are obtainable and an inquiry to the director of the library will bring information concerning them.

Industrial Notes

Construction Volume Increases.—Construction work started in the 37 states east of the Rocky Mountains during July was larger in volume than was reported for any other month since June 1931 according to F. W. Dodge Corporation. The July total, which incidentally was larger than for any other July since 1930, amounted to $294,833,800 and compares with $233,054-600 for June and with only $159,257,500 for July 1935. Of the July 1936 total, $72,093,600 was for residential buildings; $96,125,200 for non-residential buildings of all descriptions; and $126,615,000 for civil engineering jobs of all types. Total construction work started in the 37 eastern states during the first seven months of 1936 amounted to $1,532,564,500 as against only $855,764,300 for the corresponding seven months of 1935.

Unusual Features of New Turbine Generators.—Outstanding among equipments now under construction by the General Electric Co., Schenectady, are two 60,000-kw hydrogen-cooled turbine generators and one 75,-000-kw unit. Hydrogen cooling, while new in its application to turbine generators, has been used in building 375,000 kva of GE synchronous condensers. The two 60,000-kw turbine generators are being made for the jointly owned Windsor station of the Ohio Power Co. and the West Penn Electric Co. at Beach Bottom, W. Va. The turbines will be the largest high-pressure, non-condensing, high temperature machines yet built; and the generators will be the largest to operate at 3,600 rpm, as well as the largest to be hydrogen-cooled. The machines are designed for 1,250 pounds gauge pressure, 925 degrees F total temperature, and 235 pounds gauge back pressure. They will be superimposed on the existing equipment. The capacity of the Cahokia Station of the Union Electric Light & Power Co. of Illinois, at St. Louis, will be increased early in 1938 with a 75,000-kw turbine generator, which will be similar to the one, also built by General Electric, which was installed in 1928. The unit, the largest to have been ordered by any utility in recent years, will operate at 315 pounds pressure, 725 degrees F, and one inch absolute back pressure.

Armco Grants Patent License.—The Granite City Steel Co. of Granite City, Ill., has been granted a license by The American Rolling Mill Co., Middletown, O., to use its continuous sheet rolling patents and cross rolling patents, according to an announcement by Charles R. Hook, president of the latter organization. With the completion of this new continuous mill, the Granite City plant will be completely equipped for the production of hot and cold reduced sheets.

Explosion-Proof Gearmotors.—A new line of single reduction explosion-proof gearmotors ranging in size from $1^{1}/_{2}$ to 75 horsepower has been announced by the Westinghouse Electric & Mfg. Co. For application in class 1, group D hazardous locations where speed reduction is required, these gearmotors have many uses because of their compact design and high efficiency. Built to carry the maximum torque the motors will develop, the gears are of the single helical type, heat treated to provide maximum load-carrying capacity and utmost resistance to wear and shock. Anti-friction bearings assure high efficiency and maintain correct gear center distances.

Trade Literature

Controllers.—Index to bulletins and price sheets, 8 pp. Describes available literature on a complete line of industrial electric control apparatus. Allen-Bradley Co., Milwaukee, Wis.

Floodlighting Equipment.—Bulletin GEA-1865B, 28 pp. Describes Novalux floodlighting equipment. Installations are illustrated, together with complete descriptions of projectors. General Electric Co., Schenectady, N. Y.

Fans and Blowers.—Catalog FB-45, 64 pp. Contains complete specifications of Ilg self-cooled motor propeller fans and universal blowers. Applications are illustrated. Ilg Electric Ventilating Co., Chicago.

Circuit Breakers.—Catalog 5, Secs. 1–2, 16 pp. Describes heavy duty air circuit breakers, 5 to 10,000 amperes, 600 volts a-c; 750 volts d-c; live front, dead front, and steel-enclosed types. Roller-Smith Co., 233 Broadway, New York.

Cycle Controller.—Bulletin 447. Describes model 6088V process cycle controller, a recent addition to the Bristol line of such instruments. The new controller has adjustable features which make it applicable particularly in the rubber and molded plastic industries where variable speed controllers are essential. The Bristol Co., Waterbury, Conn.

Oil Purifiers.—Bulletin 503, 4 pp. Describes the Hydroil centrifugal purifier used for purifying insulating oil employed in transformers, circuit breakers, etc. These purifiers are complete, self-contained units consisting of centrifuge, heater, and deaerating apparatus. Outfits are stationary or portable, as preferred, and can be furnished with or without a filter press. Goulds Pumps, Inc., Seneca Falls, N. Y.

Molding Materials.—Bulletin, 48 pp. "Bakelite Molded." Contains a detailed description of the product, its characteristics, properties, and infinite number of applications in various fields of industry. Includes examples of finished products and also describes molding equipment and mold designs. Interesting tables supply specific data on physical, mechanical, and electrical properties of various types of molding materials, such as cellulose-filled, mineral-filled, and fabric base materials. Bakelite Corp., 247 Park Ave., New York.

Conduits for Electrical Conductors.—Bulletin, 32 pp., "Transite Conduit and Korduct for the Electrical Industry." Data is included on strength, resistance to corrosive soils and electrolysis and other qualities which make it possible to use Transite conduit for underground distribution systems without necessity for concrete envelopes. The book also gives full information on the use of Transite Korduct, a thin-walled type of Transite conduit for use in concrete envelopes. Numerous pictures and detail drawings show methods of application, types of plugs, pole riser caps, and the flexible fittings that enable both Transite conduit and Korduct to be laid by unskilled labor. Tables of weights and sizes available are included. Johns-Manville Corp., 22 E. 40th St., New York.

Phase Rotation Indicator.—Bulletin In. 8. Describes a new $2^{1}/_{2}$ inch, phase rotation indicator, weighing less than 13 ounces. This device consists of a small 3-phase induction motor mounted in a bakelite case and fitted with an aluminum disc, which instantly indicates the direction of phase rotation on a three-phase supply. The portable model, which can readily be carried in a pocket, is fitted with three 30-inch leads having crocodile clips of different colors. These instruments can be used on voltages of from 110 to 550 volts, 25 to 125 cycles, and are useful wherever it is necessary to know the phase rotation of a 3-phase circuit. Instruments for switchboard mounting can also be supplied in either of the $2^{1}/_{2}$ inch flush or projecting patterns. Ferranti Electric, Inc., 30 Rockefeller Plaza, New York.

Communication Cables.—Manual, "Laytex, The New Dielectric in Communication and Control Wires and Cables." Gives detailed information, graphs and tables indicating the characteristics and proper uses of the various types and gauges of "U.S." Laytex insulated communication cables, including fire alarm and police signal cables, supervisory control cables and telephone wires and cables. Laytex is an unmilled dielectric containing 85 per cent or more of purified rubber. In the simplest manufacturing process for applying the compounded latex to wire, the conductor is led into a container holding the liquid, unvulcanized compound. It then emerges vertically into a drying chamber where it is heat coagulated and dried. This process is continued until the desired thickness of insulation is obtained. Because of its high rubber content and because the rubber itself has never been broken down in the manufacturing process, Laytex provides exceptional insulating properties. Its chief advantages are the reduction in diameter of the insulated conductor, reduction in weight, superior aging qualities and perfect centering of the conductor in the Laytex insulation. United States Rubber Products, Inc., Wire Div., 1790 Broadway, New York.